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STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
DIVISION OF RESOURCES PLANNING

BULLETIN NO. 81

INTRUSION OF SALT WATER INTO GROUND WATER BASINS OF SOUTHERN ALAMEDA COUNTY

EDMUND G. BROWN
Governor

HARVEY O. BANKS
Director of Water Resources

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Well-testing equipment including United States Geological Survey well-logging equipment, Department of Water Resources mobile pump unit, and well-drilling contractor's cable tool drill rig

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STATE OF CALIFORNIA
Department of Water Resources
SACRAMENTO

December 1, 1960

Honorable Edmund G. Brown, Governor
and Members of the Legislature of
the State of California

San Francisco Bay Regional Water
Pollution Control Board (No. 2)

Gentlemen:

I have the honor to transmit herewith Bulletin No. 81 of the Department of Water Resources, entitled "Intrusion of Salt Water into Ground Water Basins of Southern Alameda County". This investigation was conducted and report prepared with funds appropriated by the 1957 Session of the California Legislature. Basic authority is provided under Section 231 of the Water Code.

This report presents a summary of the findings of a two-year study of salinity problems in ground waters of southern Alameda County. During the course of this study, particular attention was given to appraising the effects of improperly constructed, defective, or abandoned wells on salt-water intrusion conditions and subsequent degradation of the underlying ground waters.

During the course of the investigation, 100 wells thought to be contributing to the problem of water-quality degradation were subjected to detailed tests. Twenty of these wells were found to be contributing to the water-quality problem by allowing interchange of water between various gravel strata. Sixteen of these defective wells were sealed or repaired by the owners under our supervision; information concerning the remaining four wells has been referred to the San Francisco Bay Regional Water Pollution Control Board (No. 2).

Very truly yours,

Harvey O. Banks

HARVEY O. BANKS
Director

ORGANIZATION

DEPARTMENT OF WATER RESOURCES

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Chief Engineer

ACKNOWLEDGMENT

Considerable assistance was received from both the Alameda County Water District and the Alameda County Flood Control and Water Conservation District during the investigation. These agencies were instrumental in obtaining access to well sites for testing activities; and also provided facilities, equipment, and personnel to assist the department.

Valuable technical assistance, along with the use of a portable Widco Electric Logger for testing wells, was provided by the United States Department of the Interior, Geological Survey. In addition, the cooperation of the following public and private agencies is gratefully acknowledged:

United States Army Engineer District, San Francisco, Corps of Engineers
San Francisco Bay Regional Water Pollution Control Board
City of Fremont
City of Hayward
City of Newark
East Bay Municipal Utility District
Eden Township County Water District
Oro Loma Sanitary District
Union Sanitary District
F. E. Booth Cannery
Food Machinery and Chemical Corporation, Westvaco Chemical Division
Leslie Salt Company
Silva Brothers Well Drilling, Fremont
Cyril Williams, Jr., Consulting Civil Engineer, Berkeley

Grateful acknowledgment is made to the many well owners who granted department personnel access to their property for data collection and well testing.

CHAPTER I. INTRODUCTION

Water levels in many of the coastal ground-water basins of California have been below sea level for many years. Under appropriate geologic conditions, this will induce a flow of saline ocean water into the fresh water-bearing aquifers. As a consequence, these fresh-water reservoirs are continually threatened with intrusion of saline waters.

The southern portion of Alameda County, lying immediately to the east of San Francisco Bay, includes areas where local ground-water supplies have become increasingly degraded over a period of some 40 years. At first, this effect was restricted to shallow wells. As the shallow wells were abandoned, deeper wells were placed in service and provided good quality water for about a quarter century. During the past decade, however, salt water has intruded the deeper gravels and has reached some of these wells.

Authorization

Concern regarding progressive deterioration of ground-water supplies in southern Alameda County prompted local agencies to seek guidance on remedial measures from the San Francisco Bay Regional Water Pollution Control Board (No. 2) in the early 1950's. This resulted in a preliminary study of the salt-water intrusion problem by the Department of Water Resources, which was reported to the San Francisco Bay Regional Water Pollution

Control Board by memorandum entitled "Preliminary Study of the Salt-Water Intrusion Problems in Southern Alameda County", dated February 1957. This study indicated that while leaking wells were probably a major factor in salt-water intrusion, a comprehensive survey of the problem was required. Accordingly, the California Legislature included funds in the 1957 Budget Act (Item 263j, Chapter 600, Statutes of 1957) for a detailed study of salt-water intrusion conditions in this area. Basic authorization for the Department of Water Resources to conduct investigations of this nature stems from Section 231 of the Water Code.

Related Investigations and Reports

References used in connection with this study are listed in Appendix A. Direct reference to a particular publication or report is indicated by means of a number in parenthesis, for example, (1).

Several reports regarding the water supply of southern Alameda County were of particular assistance to accomplishment of this study. These include:

California State Department of Water Resources, Division of Resources Planning. "Preliminary Study of the Salt-Water Intrusion Problems in Southern Alameda County". Memorandum Report to San Francisco Bay Regional Water Pollution Control Board (No. 2). Project No. 57-2-12. Mimeographed. February 1957. (19).

----. "Recommended Water Well Construction and Sealing Standards, State of California". Bulletin No. 74. (In preparation). (20).

----. "Recommended Water Well Construction and Sealing Standards, Alameda County". Bulletin No. 84. (In preparation). (21).

California State Water Resources Board. "Alameda County Investigation". Bulletin No. 13. Preliminary Edition. July 1955. (27).

West, C. H. "Ground-Water Resources of the Niles Cone and Probable Salt-Water Intrusion into Ground-Water Supplies of Land Adjacent to Tidal Areas". Federal Land Bank of Berkeley. November 1, 1937. (83).

Area of Investigation

The area of investigation includes all of the coastal plain of southern Alameda County. It is a flat, bayward-sloping, alluvial plain bounded on the north by San Leandro Creek, on the east by foothills of the Diablo Range, on the south by the Alameda-Santa Clara County line, and on the west by the southern arm of San Francisco Bay (Plate 1). This area, termed the "bay plain area", covers about 128 square miles.

A substantial part of the western portion of the bay plain area is covered with evaporation ponds which have been utilized for a century by the salt industry for obtaining salt and other minerals from bay waters. In 1953, approximately 15,000 acres of marshlands along the western bayshore of Alameda County were utilized for this purpose (Plate 1).

Objective and Scope of the Study

The basic objective of this study, conducted between July 1957 and June 1959, was to determine the extent and causes of salt-water intrusion into the ground waters of southern

Alameda County. Emphasis was placed upon the degree to which faulty or abandoned wells were contributing to the problem.

The first step of the investigation was the compilation of readily available data bearing on the occurrence and nature of ground water in the problem area. This included information on the location of wells, drillers' logs, and historic water-level and water-quality records. It quickly became evident that more detailed information was needed regarding individual wells and ground-water conditions in the study area. To obtain this information, an extensive well canvass was made and field tests were conducted. The field tests included a surface resistivity survey and a test-hole drilling program to determine the areal extent of clay layers separating certain water-producing strata; well pumping tests to determine aquifer continuity; and extensive sampling and water-level measurement program to determine areal water quality and direction of ground-water movement; a transmissibility test to evaluate the probability of water migrating vertically through clay strata separating water-bearing gravels; and detailed well tests to determine if wells were providing a means for interchange of water between various water-producing strata.

Well locations are shown on Plate 2. Detailed descriptions and locations of wells, a cross-reference of well numbers, wells recommended to be used for water-quality and water-level monitoring, selected drillers' logs, water-level

records, mineral analyses of water from wells, results of well tests and disposition of wells tested, and related information were compiled. Due to the voluminous nature of this compilation, the data are not included with this report; however, copies have been supplied to the San Francisco Bay Regional Water Pollution Control Board, the Alameda County Farm Advisor, the Alameda County Flood Control and Water Conservation District, and the Alameda County Water District. Copies of the data compilations can be inspected at the offices of these agencies or at the Sacramento office of the Department of Water Resources.

Definitions

In this bulletin, certain terminology relating to geology, hydrology, and water quality are utilized with specific connotations. To facilitate understanding, and to avoid ambiguities and misconceptions regarding interpretation of these terms, the following definitions are presented:

Alluvium--A general term for stream-deposited, sedimentary materials, usually of recent geologic age.

Aquifer--A bed or stratum of earth, gravel, or porous stone sufficiently permeable to yield water to wells or springs.

Aquiclude--An impermeable bed or stratum of clay or consolidated rock which prohibits or substantially restricts the movement of ground water.

Confined Ground Water--A body of ground water overlain by material sufficiently impervious to sever free hydraulic connection with overlying water. Confined water moves like water in a pipeline under the influence of differences in head.

Unconfined Ground Water--Ground water in the zone of saturation that is not confined beneath an impermeable formation.

Forebay--An area of unconfined ground water which serves as the source of replenishment or recharge to one or a series of confined aquifers.

Perched Ground Water--Ground water occurring in a saturated upper zone separated from the main body of ground water by impervious material.

Ground Water Level--The elevation at which ground water stands in a well.

Degradation--Impairment in quality of water due to causes other than disposal of sewage and industrial waste, such as sea-water intrusion, adverse salt balance, or other means.

Location Designation System

The location designation system employed in this report for location of wells and other points is based upon the township, range, and section subdivisions of the Federal Land Survey. This designation system conforms to that used by the United States Geological Survey. Under the system, each section (square mile) is divided into 40-acre tracts which are lettered as follows:

D	C	B	A
E	F	G	H
M	L	K	J
N	P	Q	R

The letters I and O have not been utilized in the system because of possible confusion with numerals.

Wells within each of these 40-acre tracts are numbered according to the order in which they are located. For example, a well designated as 4S/1W-30K3, is the number of a well located in Section 30 of Township 4 South, Range 1 West. The K3 indicates that this is the third well to be numbered in the northwest quarter of the southeast quarter of that section. Since the land subdivision system referenced to the Mount Diablo Base and Meridian encompasses the entire study area, reference to the base and meridian has not been included in the well number.

In order to identify holes which have been drilled or bored specifically for test purposes, the letter "T" has been added to the well number following the quarter-quarter section letter, for example, 4S/1W-19JT1.

CHAPTER II. GROUND-WATER GEOLOGY, OCCURRENCE, AND QUALITY

Throughout the bay plain area of southern Alameda County, ground water occurs in permeable sand and gravel layers, sandwiched between clay layers. Substantial amounts of ground water underlying this area have been degraded in quality by saline water. Before attempting to make a detailed evaluation of the salinity problem, it was necessary to develop a basic understanding of local geologic and hydrologic conditions; this is summarized in the following paragraphs.

Ground-water Geology

To evaluate subsurface conditions which influence the occurrence and movement of ground water, a geologic investigation was made. This investigation was directed primarily toward determination of the depth, thickness, hydraulic continuity, and physical characteristics of various water-bearing strata and of clay layers separating them.

Physiography

The configuration of surface features (physiography) often is indicative of subsurface conditions and thus is helpful in appraising ground-water hydrology. The bay plain area is comprised of four principal physiographic elements: (1) the Mission upland area, a relatively small, elevated, stream-dissected area extending southeastward from Irvington and

Mission San Jose into Santa Clara County; (2) a marshland area, adjacent to the southern arm of San Francisco Bay; (3) Coyote Hills, an elongated range of low hills near Newark; and (4) an alluvial area lying between the Diablo Range on the east and the marshlands on the west (Plate 3).

The alluvial area comprises a major portion of the land surface in southern Alameda County and is of particular importance to this study as it is the principal area influenced by salt-water intrusion. The alluvial area is comprised principally of portions of three large alluvial cones and one small alluvial plain. The three cones are, from north to south, San Leandro, San Lorenzo, and Niles cones. These large cones have smaller alluvial cones, such as Dry Creek cone near Decoto, superimposed upon them. The small alluvial plain is known as Warm Springs alluvial plain. It consists of several small alluvial cones formed by minor streams draining upland areas to the east and extends from Irvington southeastward to the Santa Clara County line.

Water-bearing Formations

Water-bearing formations in the bay plain area of southern Alameda County include the Santa Clara formation of Pilo-Pleistocene age and late Pleistocene and Recent sediments. The latter have been grouped in this report as late Quaternary alluvium. Nonwater-bearing units underlie the water-bearing formations and are exposed at the surface in the Diablo Range to the east and in the Coyote Hills near Newark (Plate 3).

The Santa Clara formation is exposed at the surface from Irvington southeastward to the Alameda-Santa Clara County boundary. The Santa Clara formation lies on nonwater-bearing rocks and probably extends beneath late Quaternary alluvium in the bay plain area.

The late Quaternary alluvium and the underlying Santa Clara formation are so similar in lithology that it generally is not possible to differentiate between them in the logs of wells. For this investigation, it was not necessary to separate these units.

The fine-grained, tidal marshland deposits (shown on Plate 3) are of particular importance with respect to the occurrence and movement of ground water in the bay plain area. During the geologic past, the contact between marshland deposits and stream-laid alluvium has fluctuated to the east and west of the present line, resulting in interlayering of relatively impervious marshland clays and permeable alluvial sands and gravels (Plate 4). These interlayered deposits form a series of confined aquifers beneath the greater part of each alluvial cone.

Barriers Affecting Lateral Movement of Ground Water

Principal barriers to the lateral movement of ground water in the bay plain area are the Hayward fault and the Coyote Hills (Plate 3).

The Hayward fault is a pronounced structural feature which lies along the base of the hills from north of San Leandro to Niles and extends across the Niles cone to Irvington. It is a well-recognized ground-water barrier and has many surface expressions. Other faults in the area have no significant effect upon ground-water movement.

The Coyote Hills are the surface expression of nonwater-bearing, consolidated rocks which form a barrier, at depth, to the movement of ground water.

Ground-water Subareas

To facilitate discussion, the study area was divided into seven ground-water subareas (Plate 3), based upon the presence of faults or other geologic conditions that restrict the lateral movement of ground water. The three most important of these subareas with respect to salt-water intrusion, are the confined ground-water areas of the San Leandro, San Lorenzo, and Niles cones (I, II, and III, respectively, on Plate 3). The remaining subareas, and the corresponding designation on Plate 3, are: the forebay area for the Newark aquifer of the Niles cone (IV); Stivers alluvial area (V); Warm Springs alluvial plain (VI); and Mission upland area (VII).

San Leandro (I) and San Lorenzo (II) Cones. Water-bearing deposits extend to a maximum depth of about 1,000 feet in the San Leandro and San Lorenzo cones and ground water generally occurs under confined conditions. Aquifers, or water-bearing sand and gravel layers, in these two northern cones

were not studied in the same detail as those in the Niles cone to the south since no evidence of salt-water intrusion was found. Although aquifers within these two cones were delineated to some extent, they were not named. These aquifers are thinner and less extensive than those in the adjoining Niles cone. Water wells in the San Leandro and San Lorenzo cones are drilled to considerably greater depths than in the Niles cone and generally are perforated in more than one aquifer or are constructed with gravel envelopes to obtain comparable production.

There appears to be an upper confined aquifer occurring between the land surface and a depth of about 150 feet in each of the two northern cones, another between 150 and 250 feet in depth, and a third at a depth of about 300 feet (Cross-sections E-E' and F-F', Plate 4). For identification, these aquifers are considered to be "equivalent to" the Newark, Centerville, and Fremont aquifers of the Niles cone.

There is a minor perched aquifer in the Valle Vista area, between the communities of Mt. Eden and Decoto. This aquifer overlies the clay layer that confines the Newark (upper) aquifer and contains unconfined ground water. Only a few domestic wells, generally less than 50 feet in depth, tap this aquifer. Water-bearing materials are principally sand and yield relatively small quantities of water to wells.

<u>Niles Cone (III and IV)</u>. For convenience in discussion, the Niles cone area was divided into two subareas:

(1) the confined ground-water area (III); and (2) the forebay (recharge) area for the Newark (upper) aquifer (IV). Water-bearing deposits have been found at depths as great as 750 feet in the confined ground-water area and to 400 or 500 feet in the forebay area.

As the confined ground-water area of the Niles cone (III on Plate 3) has been affected critically by salt-water intrusion, subsurface geologic conditions within this subarea were studied in detail. The aquifers were delineated and named to facilitate discussion in this report (Cross-sections A-A' to D-D', Plate 4). From the surface of the confined ground-water area of the Niles cone to a depth of approximately 400 feet, a number of aquifers occur as distinct hydraulic units. The Newark aquifer extends to a maximum depth of about 175 feet, the Centerville aquifer occurs between 190 and 240 feet, and the Fremont aquifer is found between approximate depths of 250 and 300 feet. These aquifers are relatively thick and extensive, and are separated from one another and confined by blue clay layers. The gravel layers become thinner and contain more fine-grained materials with increases in distance from the point where Alameda Creek debouches from Niles Canyon onto the bay plain. All of these aquifers are confined and their confining clay layers extend westward beneath the floor of San Francisco Bay (Bay Cross-section on Plate 4). Aquifers below a depth of 400 feet are believed to be relatively continuous

across the San Leandro, San Lorenzo, and Niles cones (Cross-section F-F', Plate 4). Below this depth, there are three or more aquifers in the Niles cone, each of which appears to be a separate hydraulic unit.

The extent of the area considered to be the forebay or replenishment area for the Newark aquifer of the Niles cone (IV, Plate 3) is based on data obtained from well logs and from logs of test holes. Wells within this area are generally less than 150 feet deep and penetrate coarse gravels and sands interspersed with thin, discontinuous lenses of yellow clay.

Two minor perched or semiperched aquifers overlie the clay layer confining the Newark (upper) aquifer of the Niles and San Lorenzo confined ground-water areas. One of these minor aquifers is located in the Valle Vista area and the other near Newark. The area containing perched water near Valle Vista overlaps the boundary between the Niles and San Lorenzo cones, and was described in foregoing paragraphs regarding the San Leandro and San Lorenzo subareas. The aquifer near Newark overlies the clay layer confining the Newark aquifer to an unknown extent and yields limited quantities of water to wells.

Stivers Alluvial Area (V). Ground water is found in the Stivers alluvial area at elevations above sea level, and is separated hydraulically from areas to the west by the barrier effect of the Hayward fault. Accordingly, movement of saline water across the barrier is improbable and little attention was given to the area during this investigation.

Thicknesses of water-bearing deposits in the Stivers alluvial area are unknown. Ground water probably occurs under unconfined conditions.

Mission Upland Area (VI). The Mission upland area is located east of the Hayward fault and is separated hydraulically from ground-water areas to the west. As intrusion of saline water is improbable, this subarea also received only limited attention during this study. Ground water in the Mission upland area probably is confined.

Warm Springs Alluvial Plain (VII). The Warm Springs alluvial plain is underlain by finer-grained sediments than the alluvial cones to the north (Cross-section B-B' on Plate 4). Water wells penetrate thick sections of brown and yellow clay, and sandy clay which contain thin layers of water-bearing sand and fine gravel. Ground water is confined. Wells 200 or more feet in depth generally are perforated continuously from a depth of about 50 feet to the bottom. Since there were no indications of salt-water intrusion, only limited studies were made in this subarea.

Ground-water Occurrence

The locations and depths of wells were determined by an extensive well canvass of the area. Water levels in these wells further characterize the occurrence of ground waters and indicate the direction of movement of these waters.

Wells

In the San Leandro and San Lorenzo cone subareas (I and II, Plate 3), there are an estimated 4,400 wells.

It was found that a shallow well had been constructed at almost every residence in the San Leandro-San Lorenzo area to provide water for lawns and gardens. An accurate accounting of shallow wells in these subareas was beyond the purview of this study; however, several different analytical methods indicate that there are about 4,000 wells less than 50 feet deep in these subareas.

As deeper wells are more significant to the salt-water intrusion problem, more concerted efforts were made to obtain comprehensive data on wells more than 50 feet deep. A total of 315 wells were found which produced water from the depth interval between 50 and 200 feet; 100 wells produced from depths in excess of 200 feet.

In the forebay and confined ground-water portions of the Niles cone area (III and IV, Plate 3), it is believed that the locations of most of the deeper wells were established during this investigation, although many of the older, shallow wells could not be found. Well records indicate that there are approximately 360 active wells and 50 abandoned wells penetrating the Centerville and Fremont aquifers in the Niles cone. There are approximately 740 operating wells and 210 abandoned shallow wells (Plate 2).

In the Stivers alluvial area (V, Plate 3), 182 active and 35 abandoned wells were found.

In the Mission upland area (VI, Plate 3), 35 operating and 12 abandoned wells were located.

In the Warm Springs alluvial plain area (VII, Plate 3), 85 active and 20 abandoned wells were found.

Water Levels

The slope of the water surface in wells is indicative of the direction of ground-water movement. Accordingly, concerted efforts were made to obtain records of water-level measurements made in the past, as well as to develop comprehensive information regarding recent fluctuations in water levels. To provide a uniform basis for comparison, all water-level observations made during this study were converted to the mean sea level datum recently established by the United States Coast and Geodetic Survey for the San Francisco Bay Area.

Historic Water Levels. Records of ground-water level measurements in southern Alameda County begin as early as the 1890's. Water Supply Paper 345H of the United States Geological Survey (66), and records of the East Bay Municipal Utility District and the Alameda County Water District provide the most complete data.

Originally, ground-water surfaces sloped toward San Francisco Bay. Ground water probably moved into the bay from water-bearing zones in the bay plain area. However, water

levels in portions of the Niles cone have been below sea level since about 1913. In general, water levels throughout the area have been progressively lowered by continued overdraft.

Recent Water Levels. During this investigation, measurements of depths to water were made for the entire study area during the fall of 1957, spring and fall of 1958, and the spring of 1959. Lines of equal elevation of ground water (ground water contours) for the Newark and Centerville aquifers of the Niles cone during the fall of 1958 are shown on Plate 5.

During the fall of 1958, water levels in upper aquifers of the San Lorenzo and San Leandro cones sloped from elevations of about 45 feet above sea level at the foothills south of Hayward, to 5 feet above sea level near the bay (see Plate 5). At the same time, water levels in deeper aquifers were about 90 feet below sea level near Tennyson Road in Palma Ceia Village, and several miles to the northwest, near the mouth of San Lorenzo Creek in San Lorenzo, pressure levels in deeper wells were about 100 feet below sea level. At these localities, water levels in the deeper aquifers appeared to be the lowest of any in the San Leandro and San Lorenzo cone subareas.

Water levels in substantial portions of the Niles cone have been below sea level for many years. During the fall of 1958, it was determined that in the Newark aquifer the water surface sloped landward toward a trough in the vicinity of Centerville (Plate 5). Water levels in the Centerville aquifer

were below those in the Newark aquifer and sloped bayward from the apex of the Niles cone (Plate 5). In the Centerville area, the differential head between the Newark and Centerville aquifers typically varied from about 10 feet in March to about 40 feet at the height of the pumping season in late summer. Aquifers lying below the Centerville aquifer indicated pressure levels almost identical with those of the Centerville aquifer, although hydraulic connection probably exists only in the forebay area.

Water levels throughout the remainder of the bay plain area were above sea level during the study period.

Ground-water Quality

During the conduct of this study, antecedent water quality data were compiled and evaluated. In addition, water samples were collected routinely as a part of the well canvass. In areas where salt-water intrusion was detected, numerous supplementary water samples were collected and analyzed for chloride content.

Ground waters of the bay plain area can be segregated into two distinct categories: (1) those occurring generally throughout the major part of the area, except for the Niles cone; and (2) those produced from the Niles cone where extensive areas have been affected by salt-water intrusion.

Ground waters outside the Niles cone area generally are a calcium bicarbonate to calcium-sodium bicarbonate-type of fairly good quality. Chloride concentrations generally are

less than 150 parts per million (ppm), and the waters are suitable for most uses (Plate 6). Exceptions to this include waters from very shallow strata tapped by wells, generally less than 50 feet deep, in the San Leandro, San Lorenzo, and Newark areas. These waters usually are higher in salt content than waters found at greater depths, but still are suitable for some uses. Shallow, perched waters that occur in the Valle Vista area are rather high in salt content, probably as a result of concentration by evaporation or transpiration of water from the high-water table (Plate 5). These waters generally are of poor quality and unsuitable for most uses. Along the Mission fault in the Stivers alluvial area (V, Plate 3), ground waters contain high mineral concentrations although they are used for irrigation.

Ground waters from the Newark aquifer of the Niles cone are extremely variable in quality. In general, ground waters found in a strip about two miles wide along the base of the foothills are calcium bicarbonate in character and contain less than 1,000 ppm of total dissolved solids. They would be considered as good quality for irrigation use, but very hard for household use. A few wells in the vicinity of geologic faults near Niles produce water with higher mineral concentrations, particularly boron. West of old Highway 17 (Fremont Boulevard), which is about five miles easterly from the bay and roughly parallel to the shoreline, water from the Newark aquifer of the Niles cone is generally of poor quality. However, there is a tongue of relatively good-quality water about

one mile wide which extends northeasterly from Coyote Hills. Throughout the remainder of the Niles cone area, chloride concentrations in the Newark aquifer range from about 300 to 1,000 ppm along Fremont Boulevard to as high as 20,000 ppm along the bayshore near Dumbarton Bridge.

Waters from the Centerville aquifer of the Niles cone generally are calcium bicarbonate in character with chloride concentrations of less than 100 ppm. These waters are of good quality for irrigation although very hard for household uses. There are four isolated small areas north and west of Centerville and another directly east where chlorides exceed 350 ppm. In addition, there are two large areas, each embracing about two square miles, southwest and south of Centerville where chlorides exceed 350 ppm; chloride concentrations as high as 3,000 ppm are found within one of these areas. Another area, near the Dumbarton Bridge approach, produces water with chloride concentrations of 18,000 ppm, roughly the same as bay water.

With the exception of an area of about one square mile southwesterly from the sugar plant between Decoto and Alvarado where chloride concentrations exceed 350 ppm, waters from the Fremont aquifer of the Niles cone are of the same general quality as those from the Centerville aquifer.

CHAPTER III. SALT-WATER INTRUSION

There is an expanding literature on the degradation of ground waters by salt-water intrusion. The sources, mechanics, and effects of the intrusions vary widely from place to place. Information on various aspects of the problem may be obtained from readily available publications (17, 18, 33, 51, 61, 71, 72, and 80). It is considered sufficient for the purposes of this report to discuss only those particulars which lead to an evaluation of natural and man-made means for entry of salt water into the deeper ground waters of the Niles cone area.

It should be noted that as any water travels along an underground route, it will in time change its mineral character to a degree which is dependent upon the chemical composition of the materials forming the strata. Particularly, the composition of sea water may be expected to be altered by contact with clay minerals or by bacterial action on sulfates. However, the chloride concentration remains relatively unchanged (72), and is used herein as an indicator of salt-water intrusion. In consonance with previous studies, a chloride content of 350 ppm, or more, is utilized in this investigation as a criterion for waters that have been affected by salt-water intrusion (19, 27).

History

Intrusion of ground waters by saline bay water became evident in the Niles cone area in 1924, although some shallow

wells near the town of Alvarado showed quality degradation as early as 1920 (83). Commencing in 1924, the situation became increasingly alarming. By 1928, the Newark aquifer in a large portion of the area bayward from Fremont Boulevard (old Highway 17) contained water that was unsuitable for irrigation use. About this time, ranchers began drilling wells about 200 feet in depth into the Centerville aquifer. This aquifer is protected from the Newark aquifer by a thick layer of clay. Because of this new source of water supply, the seriousness of incipient salt-water intrusion was not fully recognized.

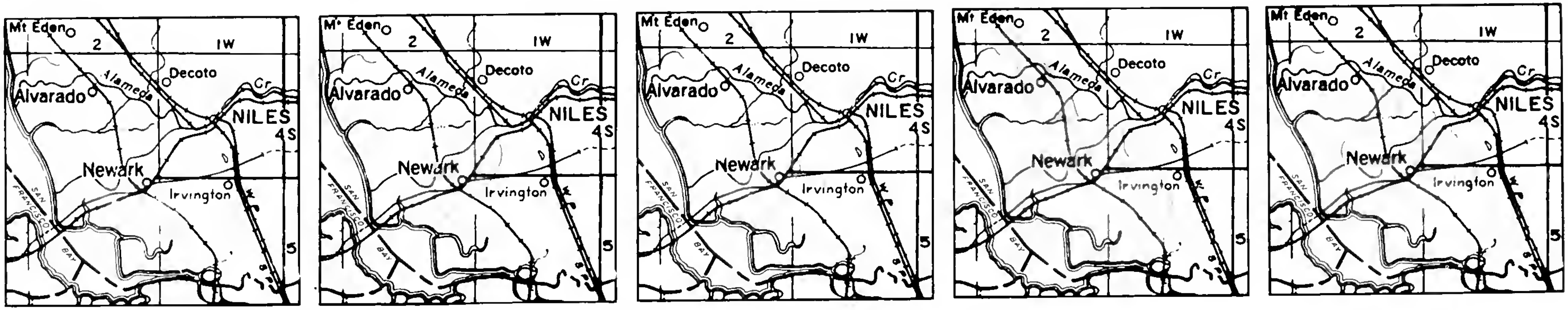
During the six-year period from 1936 to 1942, there was a moderate improvement in the quality of water from shallow wells, probably due to effects of above normal rainfall. In 1950, and again in 1957, however, it was found that bay water had intruded further inland in the Niles cone area. The progressive degradation of waters in the Newark aquifer is illustrated on Figure 1.

Prior to 1950, there was no significant degradation in the Centerville aquifer of the Niles cone, although it had been reported that saline water was evident in deep wells close to the bay in the Alvarado-Newark area (28). Little attention was given to these reports, as the more productive wells in the area continued to produce good-quality water.

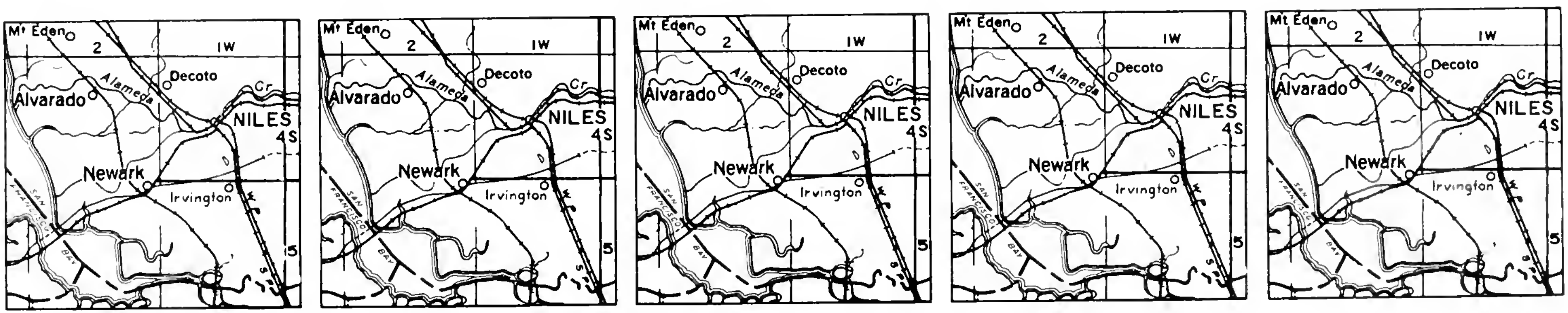
In late 1950, two deep wells penetrating the Centerville aquifer in the Centerville district, over five miles inland from the bay, produced degraded water. About the same time, other

FIGURE 1

1920 1930 1940 1950 1958



SHALLOW GROUND WATER



DEEP GROUND WATER

INDICATES WATERS WITH CHLORIDE CONCENTRATIONS EXCEEDING 350 PPM

SCALE OF MILES

0 2 4 6 8 10 12

DEGRADATION OF SHALLOW (NEWARK AQUIFER) AND DEEP (CENTERVILLE AQUIFER) GROUND WATER

deep wells in the vicinity of Newark and Alvarado were reported to be yielding salt water. By the end of 1950, about 100 acres of the Centerville aquifer produced water with chloride concentrations in excess of 350 ppm; this area of degraded water increased to about 230 acres early in 1951.

Information collected by the Department of Water Resources during a county-wide water resources investigation indicated that 660 acres of the Centerville aquifer were degraded by salt-water intrusion during the winter of 1953-54 (27). A few years later, in 1956, a reconnaissance survey indicated an alarming increase in the area affected (19).

By late 1958, about 2,630 acres of the Centerville aquifer were affected (Plate 6). Samples collected during 1959 show that about 3,000 acres were degraded by salt water.

The foregoing observations, summarized on Figure 1, clearly show a progressive increase in the area of degraded water in the Centerville aquifer.

Plate 6 shows an isolated area in the vicinity of Alvarado and Newark where water of the Fremont aquifer was found to be degraded in 1959. It is important to note that degradation of this aquifer has begun.

Entry and Movement of Saline Waters

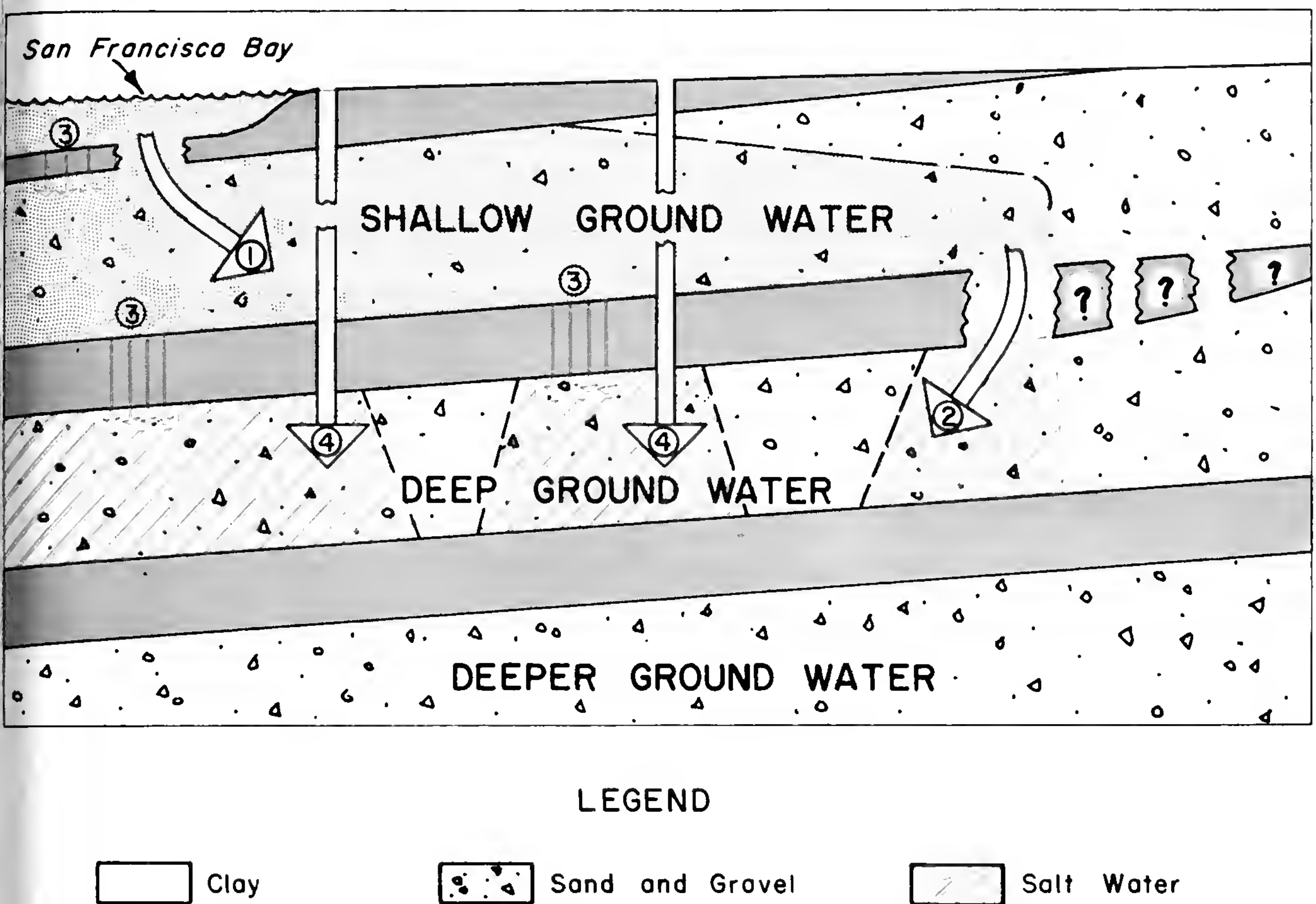
As indicated earlier, the objective of this study was the evaluation of natural and man-made factors involved in the degradation of ground waters. A general appraisal of these factors is reviewed below. The significance of the factors will be discussed in subsequent portions of this report.

Possible means for entry of salt water into ground waters are delineated on Figure 2. It is seen that there are three natural routes for subsurface movement of salt water into ground-water reservoirs. The one man-made route permits leaking or cascading of saline surface or ground water through wells. The shallow ground-water reservoir corresponds to the Newark aquifer and the deeper reservoirs correspond to the Centerville and Fremont aquifers.

Intrusion of Sea Water into the Newark Aquifer

The most probable point of entry of saline bay water into the Newark aquifer is beneath the deepest part of the tidal channel through Dumbarton Straits. Typically, bay muds and blue clay with a total thickness of about 50 feet overlie the Newark aquifer. Meandering tidal currents have eroded this material to a thickness of about 5 feet forming a "window" which extends over a width of about 2,500 feet for an undetermined distance. It is almost certain that, during maximum tidal currents, the bottom scour extends through the mud and exposes the gravels of the aquifer.

Some salt water may have entered the Newark aquifer through breaches in the clay layer underlying the tidal flats. At one time, springs existed along the western edge of Coyote Hills. Those channels through which spring water formerly flowed upward may now carry salt water downward. Pier and piling holes and abandoned water wells may also form breaches. The quantities of flow involved are relatively minor.



NOTE

1. Direct movement of bay waters through natural "windows".
2. Spilling of degraded ground waters.
3. Slow percolation of salt water through reservoir roof.
4. Spilling or cascading of saline surface waters or degraded ground water through wells.

POSSIBLE MEANS FOR ENTRY OF SALT WATER INTO GROUND WATERS

Prior to the time when water levels in the aquifer were drawn below sea level, fresh ground water must have migrated upward through the thin mud blanket. Since the 1920's, when ground water levels assumed a landward gradient, sea water has moved downward and eastward into portions of the Niles cone area.

Intrusion of Salt Water into Lower Aquifers

Subsequent to sea-water intrusion and migration into the Newark aquifer, salinization occurred in deeper water-bearing strata. Reference to Figure 2 shows that salt water has three possible means of access into the Centerville aquifer:

1. Spilling of degraded ground waters over the inland edge of the clay layer separating the Newark and Centerville aquifers.
2. Percolation of degraded ground waters through the clay layer separating the Newark and Centerville aquifers.
3. Leaking or cascading of saline surface or degraded ground waters through wells.

Spill Over Inland Edge of Confining Clay Layer. The area affected by salt-water intrusion in the Centerville aquifer, as shown on Plate 6, extends inland to the vicinity of Fremont Boulevard. If this degradation were caused by spill of saline waters from the Newark aquifer over the inland edge of the separating clay layer, it could be postulated that the clay layer should end in this vicinity. To test this hypothesis, an investigation was conducted to determine whether the clay layer was present in this area.

All available well logs in the area were compiled and examined. Most of the wells in this vicinity are shallow and information regarding the deeper strata is meager. Thus, these records were not adequate to delineate the clay layer in this area.

A second approach involved determination of the geophysical characteristics of the formations. A seismographic investigation was considered impractical, since the development of the area severely restricted the use of the small dynamite charges necessary for the observations. Accordingly, ground resistivity measurements were made at test locations shown on Plate 3. This type of survey is successful where the strata are relatively uniform and the quality of water within each formation is essentially constant. Neither of these conditions was met in the test area and results of the resistivity survey were inconclusive.

A third effort to locate the inland extremity of the clay layer between the Newark and Centerville aquifers involved the drilling of test holes. Five, 8-inch diameter holes were drilled (Plate 3), and data therefrom were correlated with logs from water wells in the vicinity. It was indicated that the blue clay layer separating the aquifers extends beneath all of Section 30 and the southeastern half of Section 19, Township 4 South, Range 1 East. Analyses of water samples obtained while drilling test holes 4S/1W-30AT1 and 4S/1W-30BT1, immediately north of Centerville, showed that water in the Newark aquifer was of poor quality. Further, north of Centerville, at test

holes 4S/1W-19JT1 and 4S/1W-19RT1, the same aquifer contained good-quality water.

The test-hole logs and past water-quality data indicated that poor-quality water in the Newark aquifer had not reached the eastern border of Section 19, north of Centerville. Further, the clay layer separating the two aquifers is present in the same area. It follows that there probably has been no spilling of degraded ground water into the Centerville aquifer. A brownish color and the presence of gravelly and sandy materials in the clay suggest that the confining layer thins rapidly and may terminate within a short distance to the northeast toward the apex of the cone. If saline waters in the Newark aquifer should migrate further inland, further information should be obtained to ascertain the integrity of this important clay layer.

Aquiclude Leakage. Laboratory and field tests were made to determine the amount of leakage through the clay layer separating the Newark and Centerville aquifers.

Laboratory measurements were made on representative test-hole samples of clay from the layer separating the Newark and Centerville aquifers. The reported values of permeability varied from 0.002 to 0.016 gallons per day per square foot (gpd/ft^2) per foot of head.

On March 13 and 14, 1959, while irrigation and industrial pumping was at a minimum, a field test was made which involved one discharge well (4S/1W-30K1) and eight observation

wells. The discharge well was pumped for 7 hours and 11 minutes. Water levels in observation wells were recorded on water stage recorders and the data were analyzed (34). A permeability of 0.0057 gpd/ft^2 per foot of head was obtained from the test. This figure is in reasonable agreement with the laboratory results.

The data obtained from these tests were utilized to estimate the amount of percolation from the Newark aquifer through the confining clay layer into the Centerville aquifer. The following assumptions were made in arriving at this estimate:

1. The differential head between Newark and Centerville aquifers typically ranges from 5 feet in late spring to 30 feet in fall (Plate 5).
2. The area of degradation in the Newark aquifer is approximately 20 square miles (Plate 6).
3. The permeability coefficient of the clay layer ranges from 0.002 to 0.016 gpd/ft^2 per foot of head.

Estimated leakage through the clay layer, based on these assumptions, ranges from 17 to 840 acre-feet per day, or 6,000 to 300,000 acre-feet per year. By way of comparison, total water use in 1958 for the Alameda County Water District, which generally encompasses the Niles cone area, was estimated at 34,000 acre-feet.[1/]

1/ Estimate submitted by Alameda County Water District to State Water Rights Board in support of application for water from Arroyo del Valle.

The higher estimate for aquiclude leakage is obviously much too large, while the lower figure of 6,000 acre-feet per year amounts to about one-sixth of the total water use. It follows that aquiclude leakage could account for a significant portion of the degradation so long as water levels in the Centerville aquifer remain lower than levels in the Newark aquifer.

To further evaluate the probability of percolation of degraded water from the Newark aquifer through the clay layer into the Centerville aquifer, a comparison was made of the distribution of chloride concentrations within the two water-bearing strata. If percolation were the major cause of degradation, high chloride areas in the lower aquifer would lie directly beneath high chloride areas in the upper aquifer, and chloride concentrations in the degraded areas would be relatively uniform. Plate 6 shows that this is not the case. The pattern of degradation in the Centerville aquifer is very spotty and differs markedly from the pattern of degradation in the Newark aquifer. The differences appear too great to be caused by variations in permeability of the clay layer separating the aquifers, even though the laboratory tests cited heretofore show an eight-fold range of permeability values.

Leakage Through Wells. As previously indicated, the pattern of salt-water intrusion in the Centerville aquifer is spotty in character and highly localized. This strongly suggests the possibility that leakage through wells is a substantial contributing factor to degradation in the Centerville

aquifer. This hypothesis is further strengthened by the fact that there are many deep wells in the areas where the Centerville aquifer is known to have been degraded by salt-water intrusion.

In order to evaluate the extent to which salt-water intrusion in the Centerville aquifer is attributable to migration of saline waters through wells, an extensive well-testing program was conducted in the Niles cone area and vicinity. This program is described in detail in the following chapter.

Prevention of Salt-water Intrusion

Although this study was not directed specifically toward evaluation of the influence of water supply on salt-water intrusion conditions, it is apparent that there can be no lasting solution to the salt-water intrusion problem without achieving a balance between ground water supply and extractions. In an area as well developed as southern Alameda County, this probably will require the importation of supplemental water for direct use or for recharge of the ground water basin. However, the proper construction and sealing of wells will tend to alleviate the problem and prolong the usefulness of the ground water basins of southern Alameda County.

CHAPTER IV. PROBLEM WELL TESTING

The major emphasis in the study of salt-water intrusion in southern Alameda County was directed toward evaluating the significance of faulty wells in the degradation of waters in deep aquifers of the Niles cone. Early in the study, a list of possible problem wells was compiled. Deep wells located in or near an area of degradation, and with one or more of the following features, were included:

1. Wells perforated in more than one aquifer.
2. Deep wells with relatively high-water levels, indicating possible entrance of water from the Newark aquifer.
3. Abandoned wells not adequately sealed.
4. Wells to be abandoned and subsequently inaccessible.
5. Wells in which indications of leakage were reported.

During the course of the investigation, certain wells were eliminated from the list, while others were added because of reported deterioration of water quality or casing defects.

The locations of the possible problem wells and their relation to chloride concentrations in waters of the Centerville aquifer are shown on Plate 7.

Attempts were made to test all suspected wells. The majority of wells tested were in the Niles cone; a few were in the northern part of the San Lorenzo cone.

The testing program was designed to determine which wells might be allowing interchange of water between aquifers, how the interchange was occurring, and to determine, if possible, the extent of degradation due to interchange of water between aquifers through wells.

During the initial testing period, it was found that many suspected problem wells could not be tested without the aid of special equipment. It was necessary, in many instances, to remove mounted pumps, to clean out debris, and to open partially-blocked or collapsed casings. The services of a water-well drilling contractor were required to accomplish the work. In addition, a cooperative agreement was made with the United States Geological Survey for use of special well-testing equipment and for aid in interpreting data obtained with this equipment.

Prior to testing, written permission to conduct necessary tests was obtained from the owner of the property on which the well was located.

Testing Procedures

Before testing each well, the site was cleared to provide operating space for the drill rig. When necessary, pumphouses, fences, power lines, and other obstructions were dismantled or removed. Next, the motor, pump column, and pump bowls were removed from the well and carefully stored nearby. The well was then subjected to the following tests:

1. If the casing of the well was filled with foreign material, it was cleaned either to original depth or sufficiently to expose from 5 to 10 feet of casing perforations adjacent to the Centerville aquifer. The material removed from the well was examined to evaluate its sealing properties.

It was necessary to exercise extreme caution when working in old or abandoned wells because the risk of collapse was often great. Many wells showed evidence of casing failure due to corrosion or rotting, while others were so crooked that it was difficult to install testing equipment without damaging the casing.

2. Water levels in wells penetrating various aquifers within a one-quarter mile radius of the well under test were measured and compared with those found at the well. These measurements permitted a determination as to which aquifer or aquifers yielded water to the well being tested.

3. A submersible pump was placed in the lower perforated area of the well and pumped for approximately two hours at rates of 50 to 100 gallons per minute. The purposes of these pumping tests were: (a) to clear standing water from the well in order to obtain samples representative of water in the Centerville aquifer at this point; (b) to determine whether there was free movement of water into the well; and (c) to determine whether the chloride content varied with pumping time.

4. A packer was placed in the well opposite the clay layer separating the Newark and Centerville aquifers. Location

and thickness of the clay was obtained from the log of the well or estimated from records for adjacent wells. With the packer in place, water-level observations were made to determine the head differential between the two aquifers. If water was entering the well from either aquifer, samples were collected and quality determined by analyzing samples of water obtained by pumping for selected periods of time.

Where the condition of the well casing precluded use of a packer, a cement plug was placed in the well at the selected depth. The use of a plug allowed the collection of water-level and quality information only from the Newark aquifer. The cement plug was removed after testing to restore the well to its original condition, unless the owner specifically requested that the plug remain in place.

5. When no interchange of water between aquifers was found to be occurring through the well casing, an additional test sometimes was made in abandoned wells. This was to determine if there was any interchange of water occurring through the annular space between the casing and the wall of the drill hole. For this determination, the casing was perforated in the lower 5 to 10 feet of the clay layer separating the Newark and Centerville aquifers. A packer was placed in the well immediately below these perforations and water levels above and below the packer were recorded.

6. Where it was indicated that the annular space outside the well casing had been filled previously with cement or other material to serve as a salinity seal, an

attempt was made in abandoned wells to determine the depth to the bottom of this seal by "feeling" with a Mills knife perforator. When the bottom of the annular space was located, geologic cross-sections of the immediate area were studied to determine if the seal was sufficient to prevent movement of saline water from the Newark aquifer into the underlying Centerville aquifer.

When a well was found to be allowing interchange of water between the Newark and Centerville aquifers, or the well's construction or condition appeared inadequate, the well owner was contacted and a determined effort was made to have the well sealed immediately, under the department's supervision. Of the 100 wells tested, 33 were sealed in this manner.

Supplemental Tests

In the event that no pump was installed in the well and the hole was open to its full depth, tests were made in cooperation with personnel of the United States Geological Survey. Twenty-five wells were tested during the period from May 5 to June 29, 1959, with a portable Widco Electric Logger (frontispiece). With this equipment, fluid-resistivity, gamma-ray, and self-potential surveys were made.

Profiles obtained by fluid-resistivity surveys show the resistivity of the column of water in the well being tested, and may indicate that the well is allowing interchange of water between aquifers. The test involved replacing all water in the well shaft with water of good quality and high resistivity. If poor-quality ground water from the Newark aquifer was entering the well through a leaky casing, a marked decrease in

resistivity of the water adjacent to the leak would be evident in the resistivity profile. Analyses of water samples obtained at depths where significant changes were indicated on the resistivity profile were made to verify the location of the leak, and permit estimation of quality of the water entering the casing.

The gamma-ray survey measures the natural gamma radiation emitted by subsurface deposits. Since clay layers generally emit more gamma rays than sand and gravel layers, the gamma-ray log can provide a basis for determining the depth and thickness of various strata. Also, as response to gamma radiation varies with size of the bore hole, thickness of casing, presence of cement plugs, and other subsurface variations, the gamma-ray survey may be of value in determining the major features of well construction.

The self-potential variations recorded on an electric log obtained in an uncased well are caused by differences in chemical quality between waters in the hole and in the surrounding formations, and from movement of water between the well and the surrounding formations, respectively. During the investigation, an attempt was made to determine if the recorded self-potential profiles obtained in a cased well would indicate the existence of a leaky casing (42, 47); however, the results were inconclusive.

Test Results

A list of 104 possible problem wells, compiled from available well records and other information obtained during the course of the investigation, formed the basis of the well testing program (see Appendix B). One of the wells had been covered and could not be located; access to three of the wells could not be obtained from property owners; and detailed tests were conducted on the remaining 100 problem wells. Results of these tests are summarized in the following tabulation:

	Active	Abandoned	Total
Possible problem wells	35	69	104
Possible problem wells tested	32	68	100
Problem wells found	3	17	20
Problem wells sealed	1	15	16
Other wells sealed	1	16	17

These tests indicated that saline waters were entering and causing degradation in the Centerville aquifer through 20 defective wells. Well owners were persuaded to seal 16 of these wells during the course of the investigation. Information regarding the remaining four problem wells, and also the three possible problem wells to which access was not obtained, was turned over to the San Francisco Bay Regional Water Pollution Control Board.

There is a definite possibility that interchange of water between aquifers may eventually occur through any abandoned well that is not adequately sealed, because of the

inevitable deterioration of well casings. Thus, every effort was made to persuade owners to seal each abandoned well that was tested, even if no leakage was found. As a result, 17 wells that were not causing degradation in the Centerville aquifer at the time of testing, but nevertheless represented potential threats to quality of ground waters, were sealed in accordance with the department's recommendations.

A comparison of Plates 2, 6, and 7 shows that a relatively small proportion of the abandoned deep wells in the Niles cone area were considered possible problem wells at the time of the field investigation. Continued surveillance and corrective action are, therefore, required to prevent further degradation of water in the deeper aquifers.

During the course of the well-testing program, it was found that an unknown number of abandoned wells close to the bay had, in the past, been subjected to flooding by saline bay water (85). Apparently, saline water had moved through the well shafts into aquifers producing fresh water and impaired the quality of water. In general, these wells cannot be located accurately in the field because they have been filled or covered by improvements in the tidal areas. The principal area where this condition exists is in the vicinity of an old well near Alvarado, although there are indications that a similar problem may occur near Coyote Hills.

Adequate sealing of all abandoned wells is considered to be essential, since the areas in which many of these wells are located are being covered by new construction which obscures the location of the wells or makes them inaccessible.

CHAPTER V. CONCLUSIONS AND RECOMMENDATIONS

As a result of this study, the following conclusions were reached. Based upon these conclusions, recommendations for protecting lower aquifers from future quality degradation and alleviating present degradation were made.

Conclusions

1. Ground waters of the Niles cone area in southern Alameda County have been significantly affected by salt-water intrusion.

2. Salt-water intrusion into the Newark aquifer of the Niles cone subarea was first noted near Alvarado in 1920. By 1928, much of the water in this aquifer was unsuitable for irrigation. Increased water use has caused the area of degradation to expand during succeeding years.

3. Sea water from the bay probably enters the Newark aquifer from the deeper part of Dumbarton Straits, through gravels which are periodically exposed by tidal currents.

4. In June 1959, salt-water intrusion in the Newark aquifer did not extend inland beyond the clay layer overlying the Centerville aquifer.

5. Degradation of ground water in the Centerville aquifer of the Niles cone subarea began in 1950 and quickly encompassed an area of 100 acres. The degraded area expanded to about 2,800 acres in 1956 and 3,000 acres in 1959.

6. The clay layer separating the Newark and Centerville aquifers of the Niles cone subarea extended past the 1959 limit of salt-water intrusion into the Newark aquifer. It is possible that aquiclude leakage could account for a significant portion of the degradation as long as water levels in the Centerville aquifer remain lower than levels in the Newark aquifer.

7. Abandoned, defective, and inadequately-constructed wells have allowed, and are continuing to allow, saline waters in the Newark aquifer to enter fresh water in underlying aquifers. The spotty occurrence of degraded water in the Centerville aquifer shows a high degree of correlation with the locations of suspected problem wells.

8. In 1959, salt-water intrusion commenced in the Fremont aquifer of the Niles cone subarea.

9. Excepting the Niles cone subarea, in general, deeper aquifers throughout southern Alameda County have not been affected by salt-water intrusion. However, the threat of such degradation, noted in earlier studies, still exists.

10. During the investigation, 100 possible problem wells were tested of which 20 were found to be allowing interchange of saline water between aquifers. Sixteen of these defective wells were sealed or repaired under supervision of the department. Information concerning the remaining four wells was referred to the San Francisco Bay Regional Water Pollution Control Board (No. 2). In addition to the 16 problem wells mentioned, 17 additional wells were sealed under department supervision.

11. Abandoned water wells often are difficult to locate and seal. Existing records show that there are some deep abandoned water wells in southern Alameda County, probably in the Niles cone area, that cannot now be located in the field. Abandoned wells are frequently covered by streets, houses, or other developments. They are considered potential problem wells because of the inevitable corrosion of well casings.

12. A permanent solution to the salt-water intrusion problem of southern Alameda County cannot be achieved until additional water supplies are imported to equalize ground water replenishment and extractions.

Recommendations

Following are recommendations for protecting lower aquifers from future quality degradation and alleviating present degradation:

1. Adopt and enforce suitable standards for water-well construction and for sealing of abandoned wells.

2. Continue the search for, and the proper sealing of, problem wells which may exist or may develop.

3. Maintain surveillance of the quality of water and water levels in all strata affected or threatened with degradation.

4. Import supplemental water to equalize ground water supply and extractions.

LEGEND

SOUTHERN ALAMEDA COUNTY

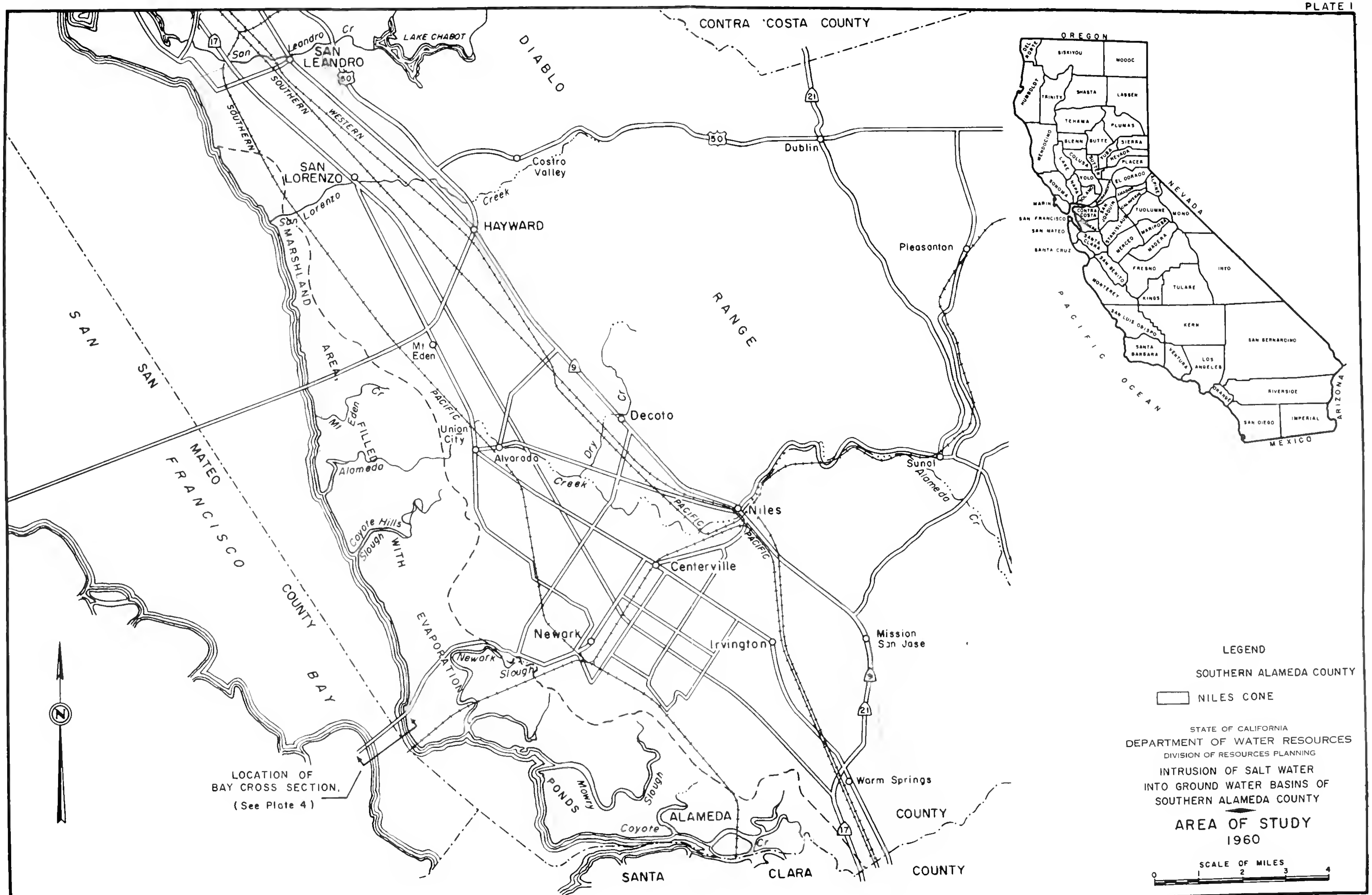
NILES CONE

STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
DIVISION OF RESOURCES PLANNING

INTRUSION OF SALT WATER
INTO GROUND WATER BASINS OF
SOUTHERN ALAMEDA COUNTY

AREA OF STUDY
1960

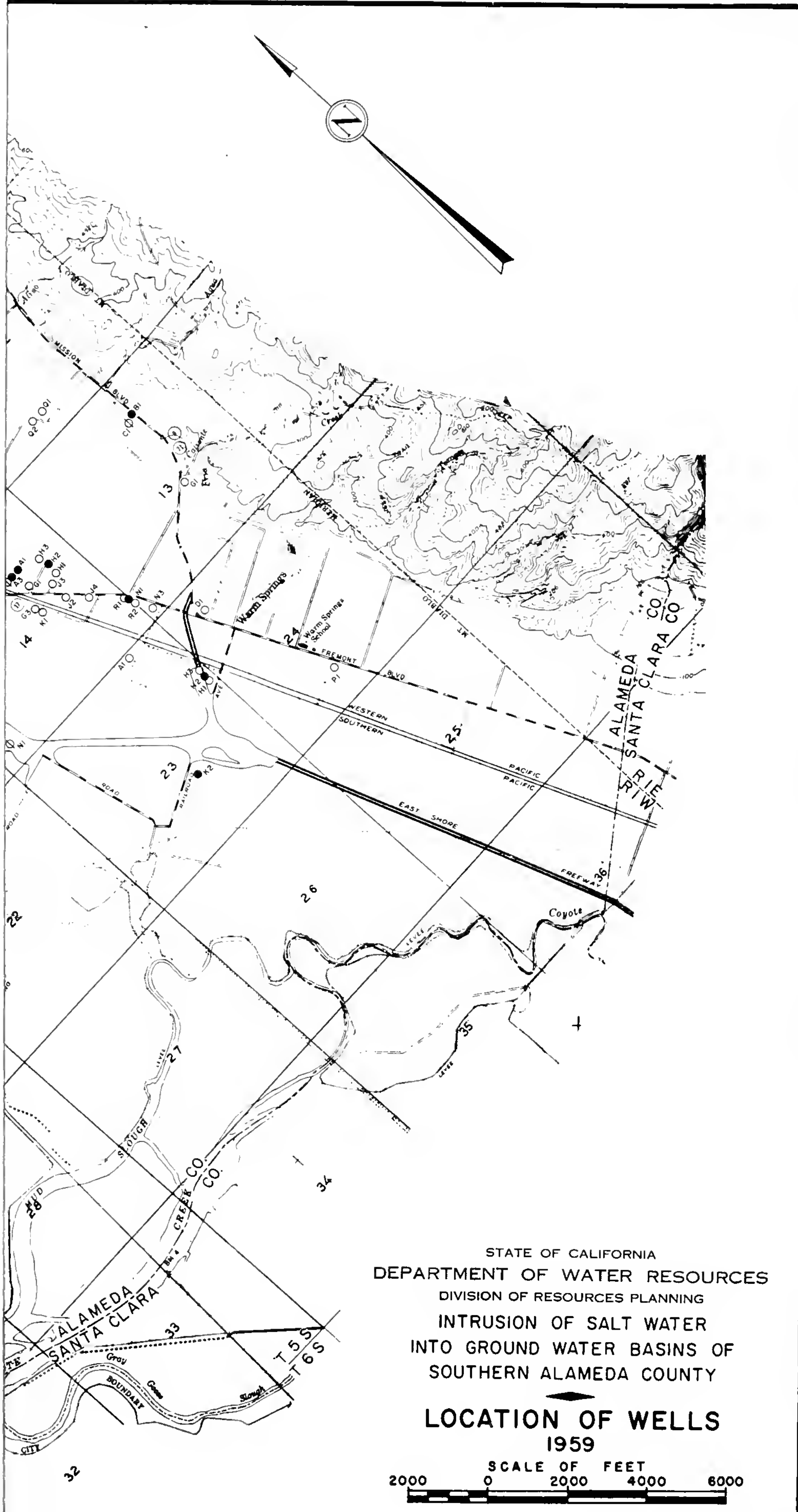
SCALE OF MILES
0 1 2 3 4



STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
DIVISION OF RESOURCES PLANNING

INTRUSION OF SALT WATER INTO GROUND WATER BASINS OF SOUTHERN ALAMEDA COUNTY

AREA OF STUDY
1960

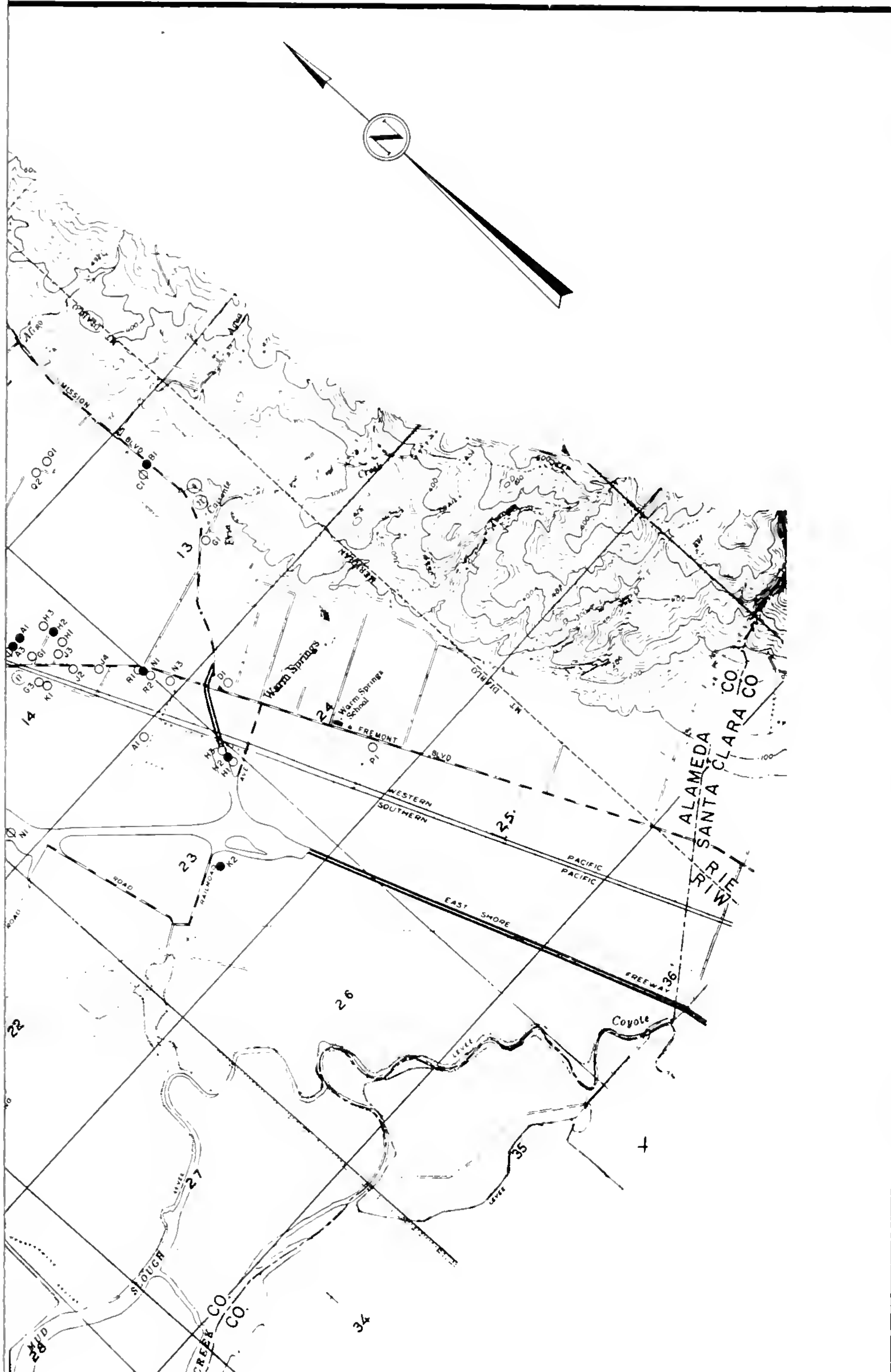


STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
DIVISION OF RESOURCES PLANNING

INTRUSION OF SALT WATER INTO GROUND WATER BASINS OF SOUTHERN ALAMEDA COUNTY

LOCATION OF WELLS
1959

SCALE OF FEET
2000 0 2000 4000 6000

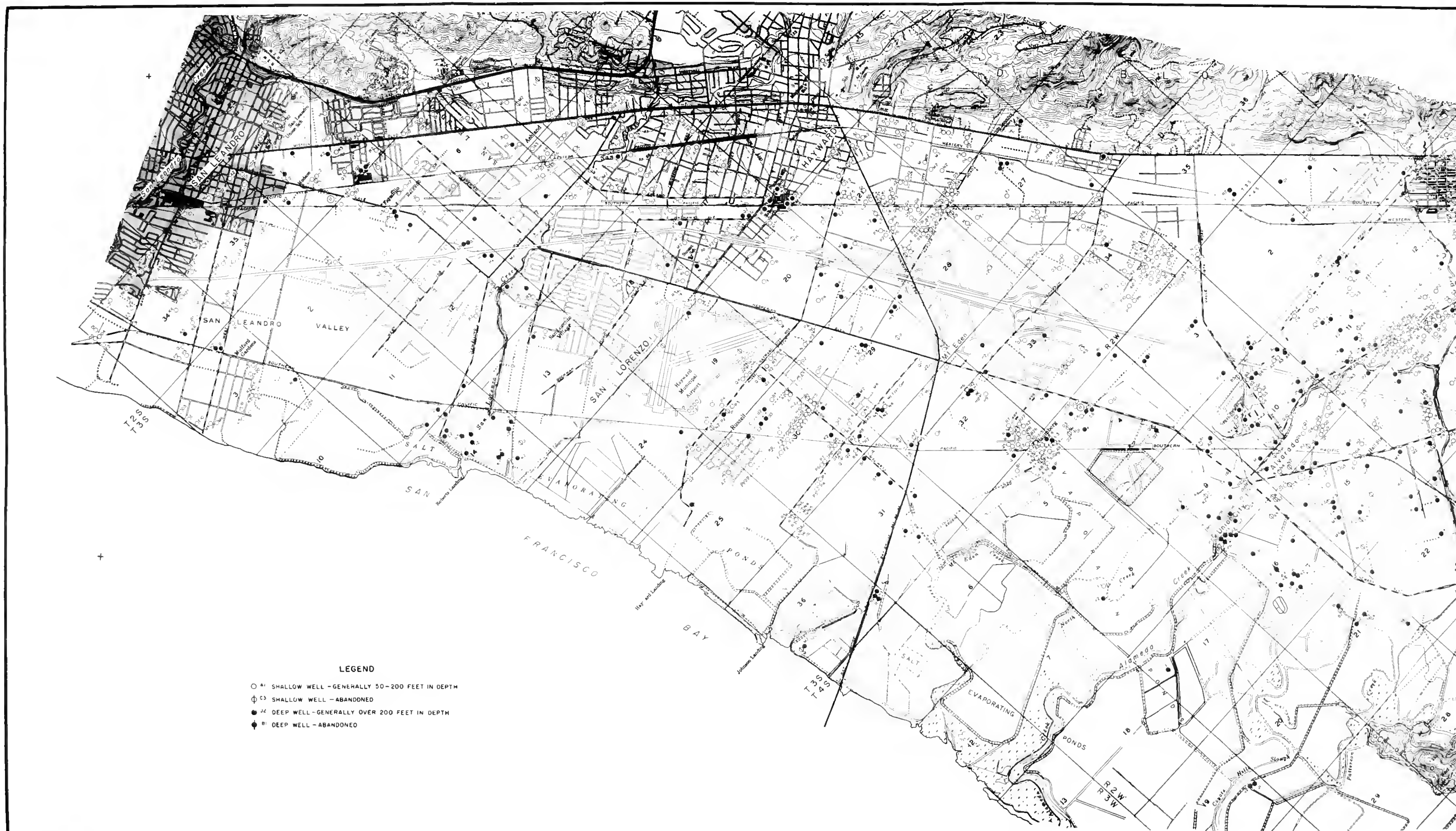


STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
DIVISION OF RESOURCES PLANNING

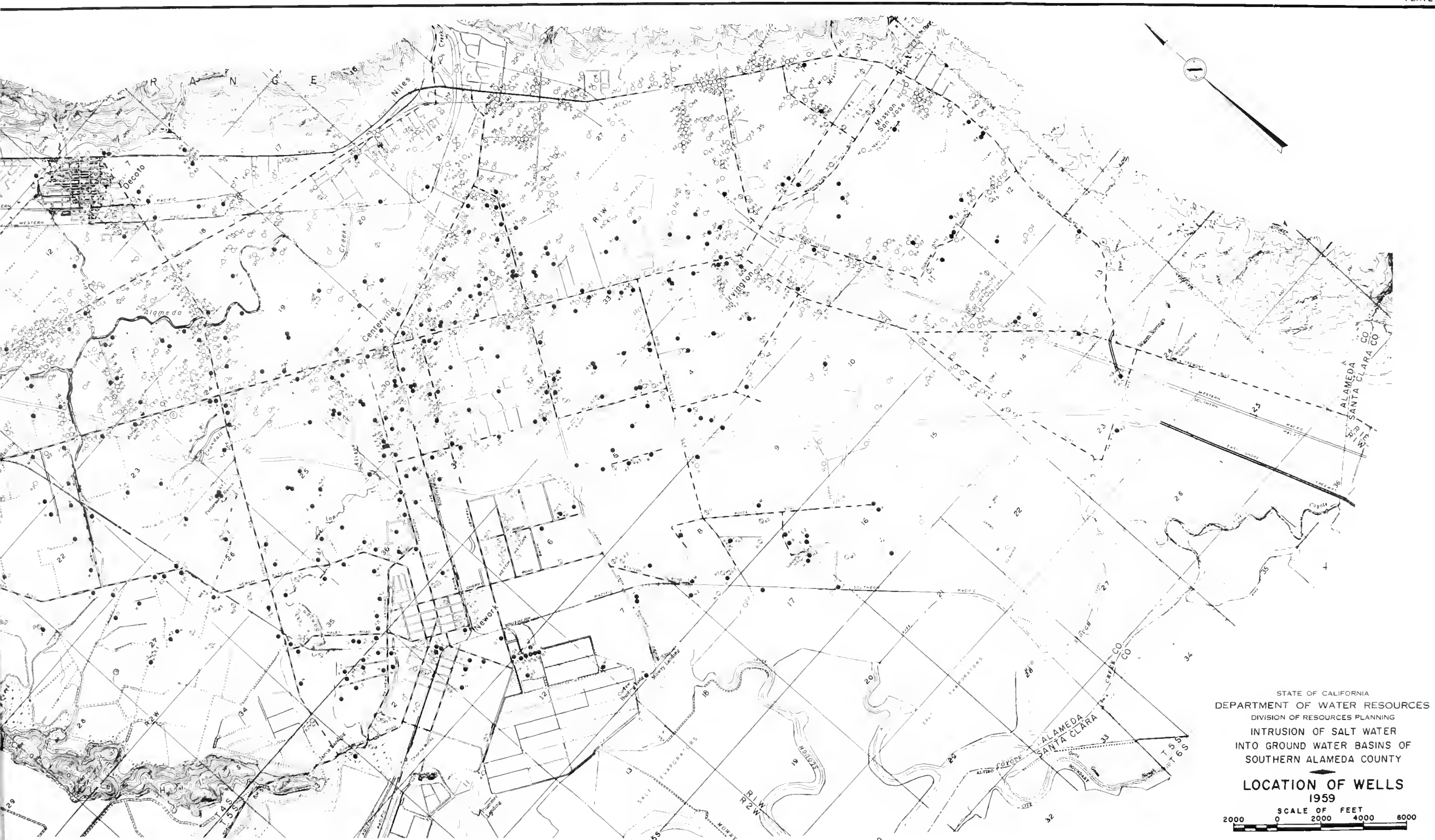
INTRUSION OF SALT WATER INTO GROUND WATER BASINS OF SOUTHERN ALAMEDA COUNTY

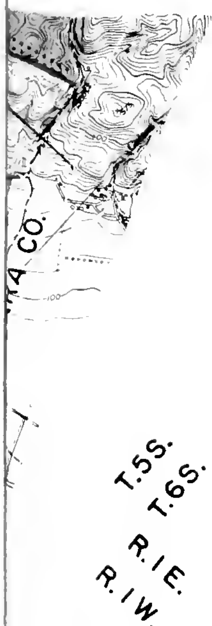
LOCATION OF WELLS
1959

SCALE OF FEET
2000 0 2000 4000 6000



SAN LEANDRO
HAYWARD
SAN LEANDRO VALLEY
SAN LORENZO
Hayward Municipal Airport
Alvarado
Union City
SALT EVAPORATING PONDS
SAN FRANCISCO BAY
T2S
T3S
T3S
T4S
R2W
R3W
LEGEND
SHALLOW WELL - GENERALLY 50-200 FEET IN DEPTH
SHALLOW WELL - ABANDONED
DEEP WELL - GENERALLY OVER 200 FEET IN DEPTH
DEEP WELL - ABANDONED


STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
DIVISION OF RESOURCES PLANNING
INTRUSION OF SALT WATER
INTO GROUND WATER BASINS OF
SOUTHERN ALAMEDA COUNTY
LOCATION OF WELLS
1959
SCALE OF FEET
2000 0 2000 4000 6000
Niles
Decoto
Centerville
Irvington
Newark
Mission San Jose
Warm Springs
ALAMEDA CO
SANTA CLARA CO
R1W
R2W
T4S
T5S
T6S



LITHOLOGIC UNITS

PRE-QUATERNARY / QUATERNARY — RECENT / PLEISTOCENE — JURASSIC TO PLIOCENE

Qal — UNCONSOLIDATED ALLUVIAL FAN DEPOSITS CONSISTING OF GRAVEL, SAND, SILT, AND CLAY

Qm — MARSH LAND DEPOSITS UNCONSOLIDATED AND CONSISTING CHIEFLY OF CLAY WITH IRREGULAR LENSES OF SAND AND GRAVEL

TQs — SANTA CLARA FORMATION. POORLY CONSOLIDATED CONTINENTAL DEPOSITS OF SAND, GRAVEL, SILT, AND CLAY.

JKT — SEDIMENTARY, VOLCANIC, AND METAMORPHIC ROCKS OF TERTIARY, CRETACEOUS, AND JURASSIC AGES. CONSIDERED TO BE ESSENTIALLY NONWATER-BEARING.

SYMBOLS

CONTACTS

- ACCURATELY LOCATED
- APPROXIMATELY LOCATED

FAULTS

- ACCURATELY LOCATED
- APPROXIMATELY LOCATED
- CONCEALED

GROUND RESISTIVITY SURVEY STATION

TEST HOLE

A — A LINE OF GEOLOGIC SECTION

GROUND-WATER SUBAREA BOUNDARY

GROUND-WATER SUBAREAS

- I SAN LEANDRO CONE CONFINED GROUND-WATER AREA
- II SAN LORENZO CONE CONFINED GROUND-WATER AREA
- III NILES CONE CONFINED GROUND-WATER AREA
- IV NILES CONE FOREBAY AREA, NEWARK AQUIFER
- V STIVERS ALLUVIATED AREA
- VI WARM SPRINGS ALLUVIAL PLAIN
- VII MISSION UPLAND

E
OGIC MAP MODIFIED FROM CALIFORNIA STATE
R RESOURCES BOARD BULLETIN 13 "ALAMEDA
TY INVESTIGATION" JULY, 1955 AND THE
ORNIA STATE DEPARTMENT OF PUBLIC
S, DIVISION OF WATER RESOURCES "GEOLOGY
OUTHERN ALAMEDA COUNTY" UNPUBLISHED
BY R G THOMAS 1950

STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
DIVISION OF RESOURCES PLANNING

INTRUSION OF SALT WATER
INTO GROUND WATER BASINS OF
SOUTHERN ALAMEDA COUNTY

AREAL GEOLOGY

SCALE OF FEET
2000 0 2000 4000 6000

D I A B L O
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SAN LEANDRO
San Leandro Creek
HAYWARD
SAN LEANDRO VALLEY
SAN LORENZO
Mt Eden
Decoto
Alameda
Alvarado
Union City
Alameda Creek
Coyote Hills
SAN FRANCISCO
BAY
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T.3S.
T.3S.
T.4S.
T.4S.
T.5S.
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R.3W.
Qal
Qm
JKT

PLATE 3


MISSION
FAULT
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Mission San Jose
HAYWARD FAULT
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Qal
Irvington
BOULEVARD
Warm Springs
Centerville
Creek
Newark
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SANTA CLARA CO.
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JURASSIC TO PLIOCENE
Qal UNCONSOLIDATED ALLUVIAL FAN DEPOSITS CONSISTING OF GRAVEL SAND, SILT, AND CLAY
Qm MARSH LAND DEPOSITS UNCONSOLIDATED AND CONSISTING CHIEFLY OF CLAY WITH IRREGULAR LENSES OF SAND AND GRAVEL
TQs SANTA CLARA FORMATION POORLY CONSOLIDATED CONTINENTAL DEPOSITS OF SAND, GRAVEL, SILT, AND CLAY
JKT SEDIMENTARY VOLCANIC AND METAMORPHIC ROCKS OF TERTIARY, CRETACEOUS, AND JURASSIC AGES CONSIDERED TO BE ESSENTIALLY NONWATER-BEARING
SYMBOLS
CONTACTS
ACCURATELY LOCATED
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FAULTS
ACCURATELY LOCATED
APPROXIMATELY LOCATED
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GROUND RESISTIVITY SURVEY STATION
TEST HOLE
LINE OF GEOLOGIC SECTION
GROUND-WATER SUBAREA BOUNDARY
GROUND-WATER SUBAREAS
I SAN LEANDRO CONE CONFINED GROUND-WATER AREA
II SAN LORENZO CONE CONFINED GROUND-WATER AREA
III NILES CONE CONFINED GROUND-WATER AREA
IV NILES CONE FOREBAY AREA NEWARK AQUIFER
V STIVERS ALLUVIATED AREA
VI WARM SPRINGS ALLUVIAL PLAIN
VII MISSION UPLAND
NOTE
STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
DIVISION OF RESOURCES PLANNING
INTRUSION OF SALT WATER INTO GROUND WATER BASINS OF SOUTHERN ALAMEDA COUNTY
AREAL GEOLOGY
SCALE OF FEET
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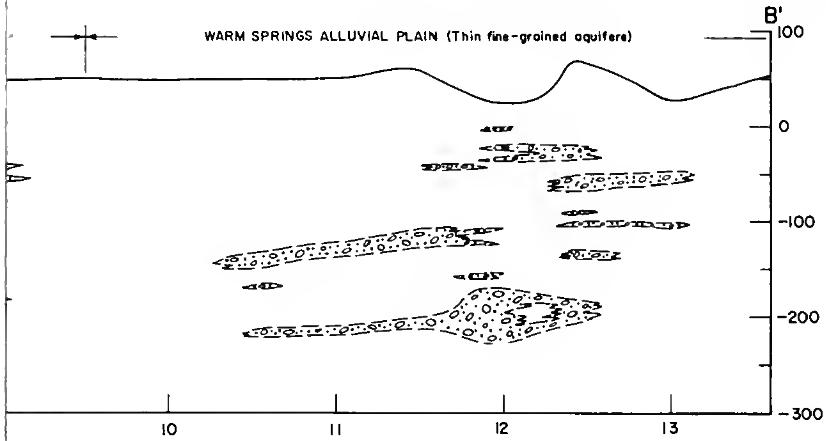

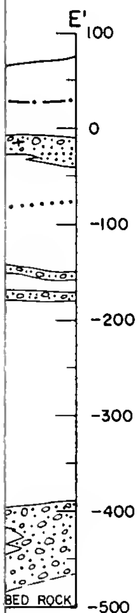

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ON OF PERMEABLE DEPOSITS CONTAINING GROUND WATER WITH CHLORIDE
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ND SILT

EVELS OCTOBER 1958

Sections
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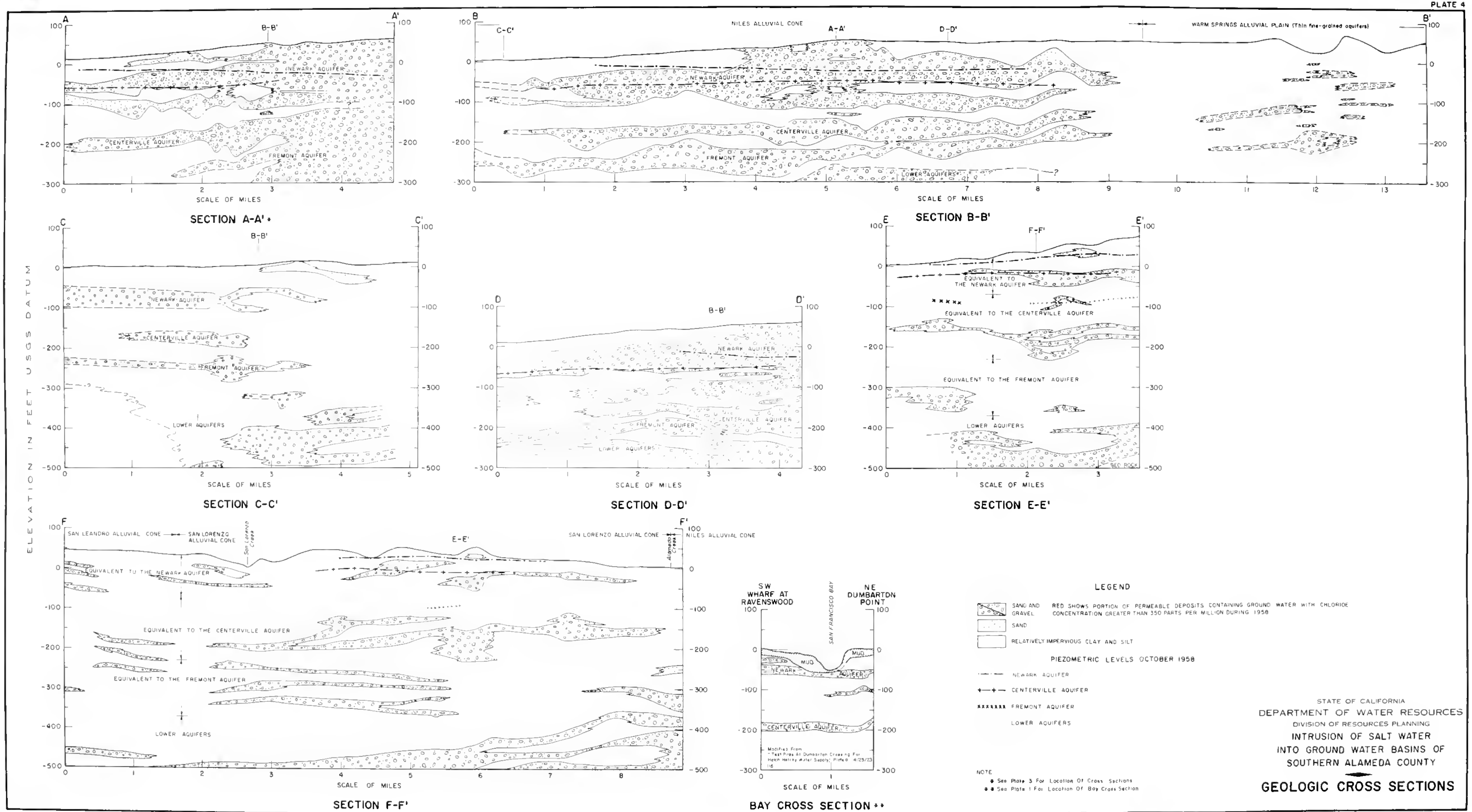
STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
DIVISION OF RESOURCES PLANNING
INTRUSION OF SALT WATER
INTO GROUND WATER BASINS OF
SOUTHERN ALAMEDA COUNTY

GEOLOGIC CROSS SECTIONS



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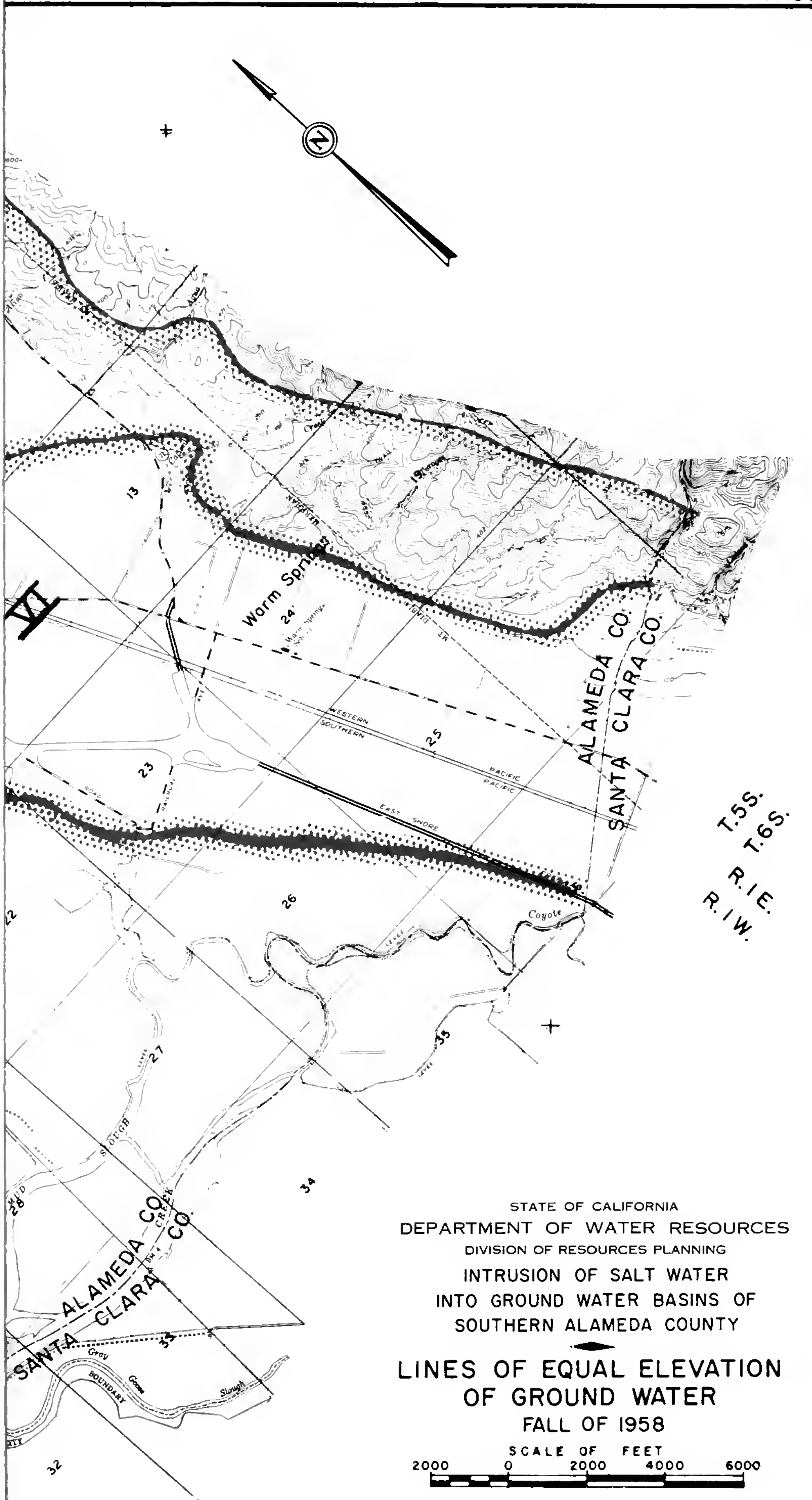

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DEPARTMENT OF WATER RESOURCES
DIVISION OF RESOURCES PLANNING

INTRUSION OF SALT WATER INTO GROUND WATER BASINS OF SOUTHERN ALAMEDA COUNTY

LINES OF EQUAL ELEVATION OF GROUND WATER

FALL OF 1958

SCALE OF FEET
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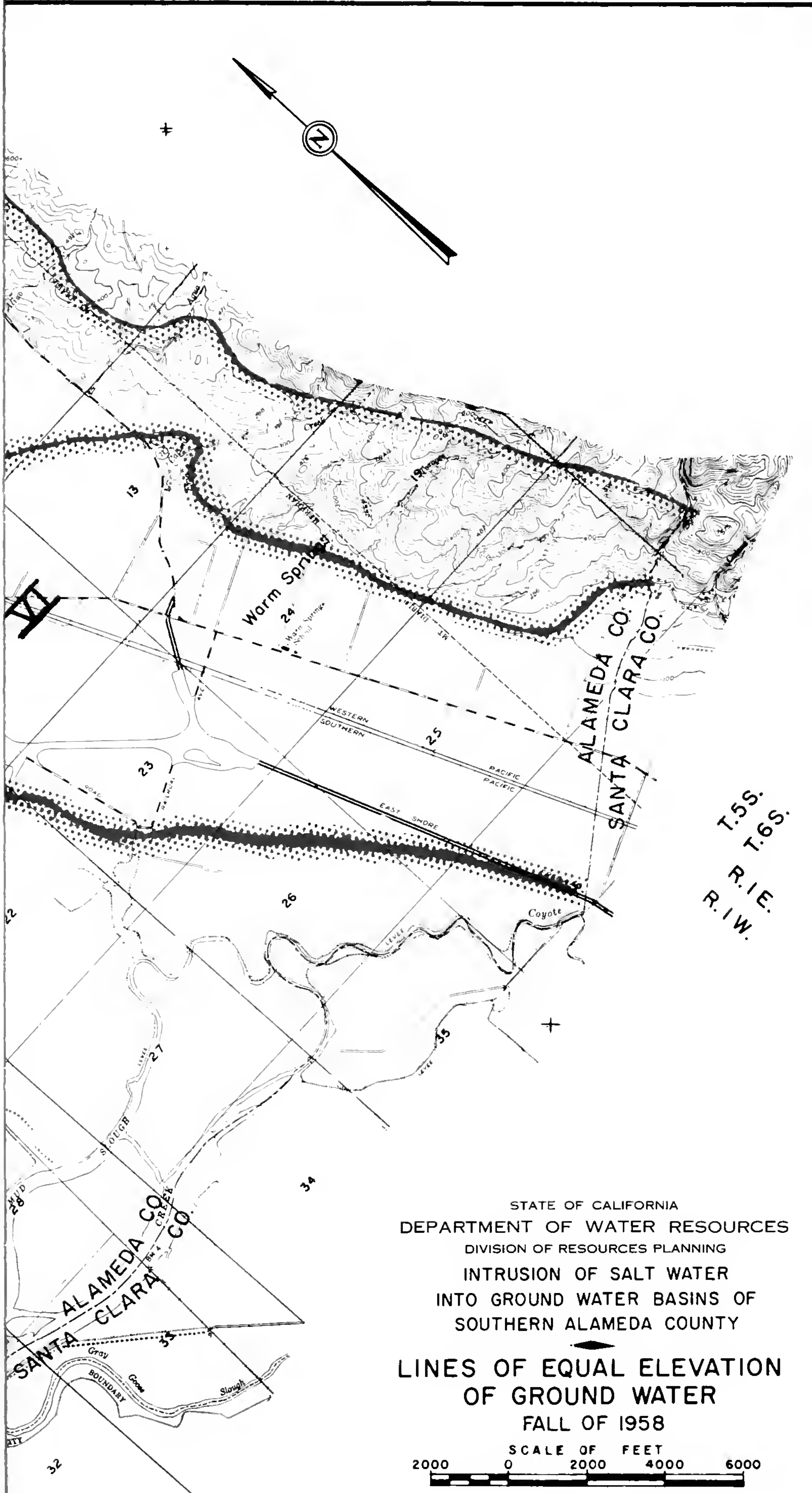

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LINES OF EQUAL ELEVATION OF GROUND WATER

FALL OF 1958

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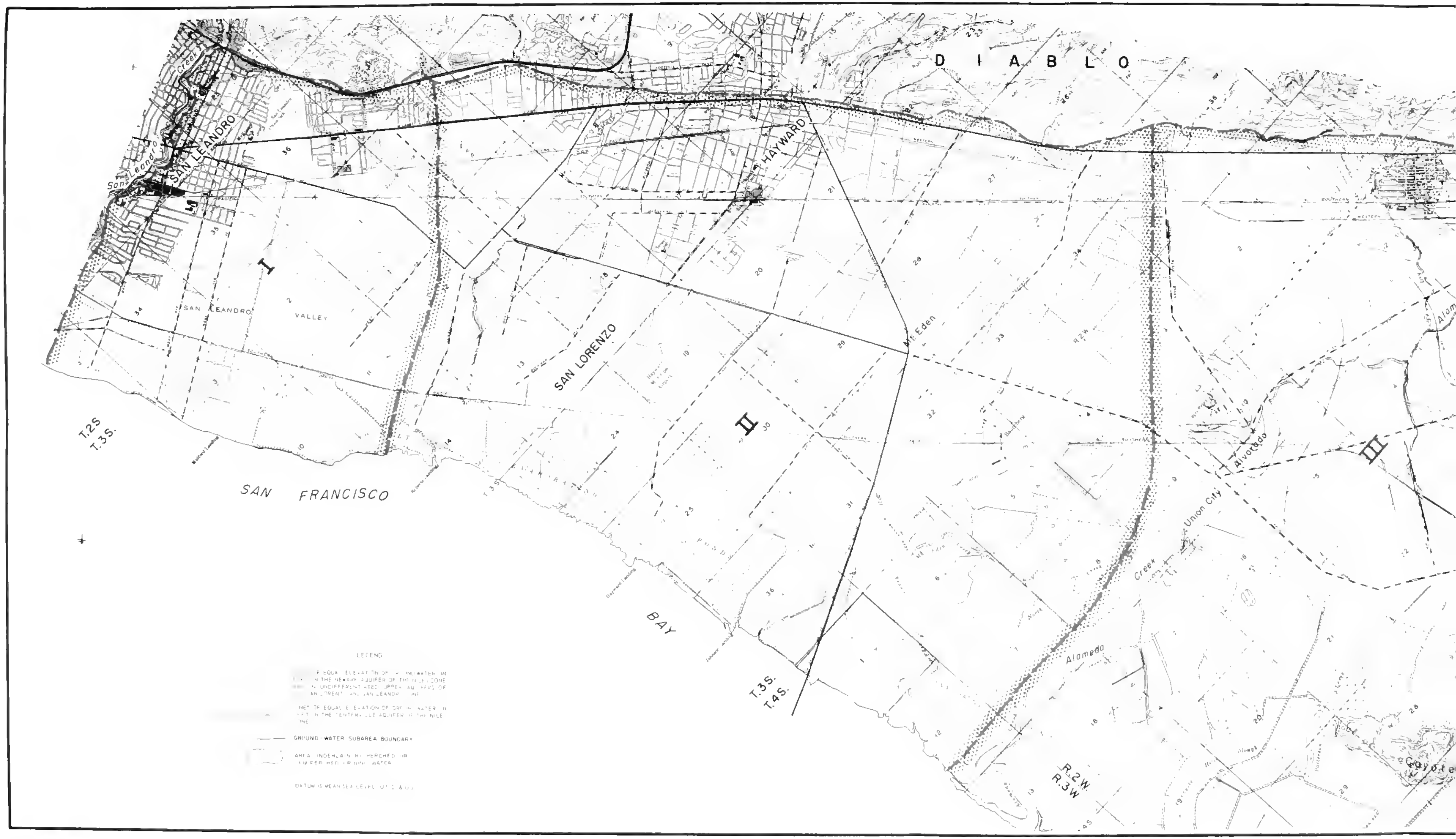

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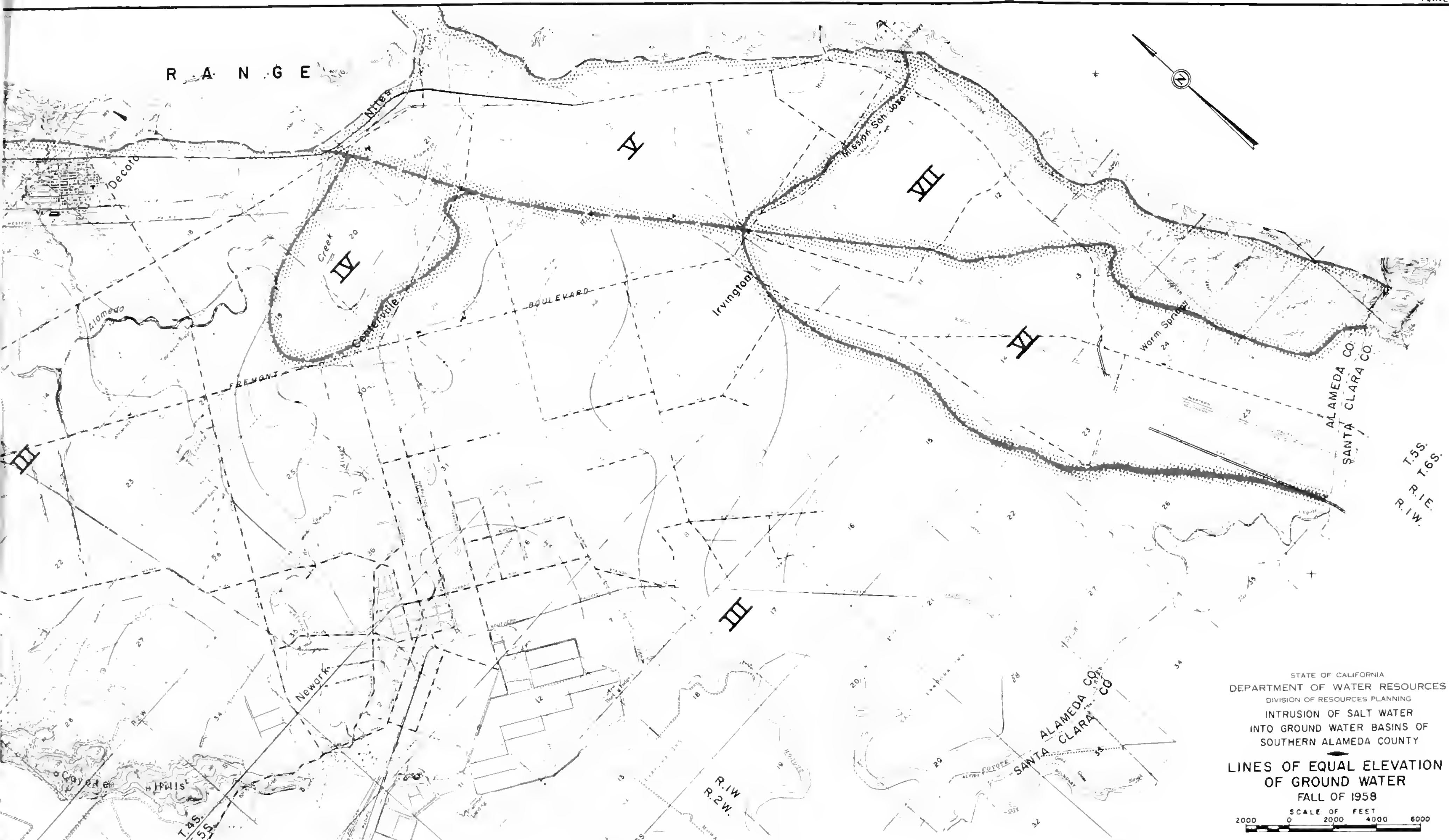
LEGEND
GROUND-WATER SUBAREA BOUNDARY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STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
DIVISION OF RESOURCES PLANNING
INTRUSION OF SALT WATER
INTO GROUND WATER BASINS OF
SOUTHERN ALAMEDA COUNTY
LINES OF EQUAL ELEVATION
OF GROUND WATER
FALL OF 1958
SCALE OF FEET
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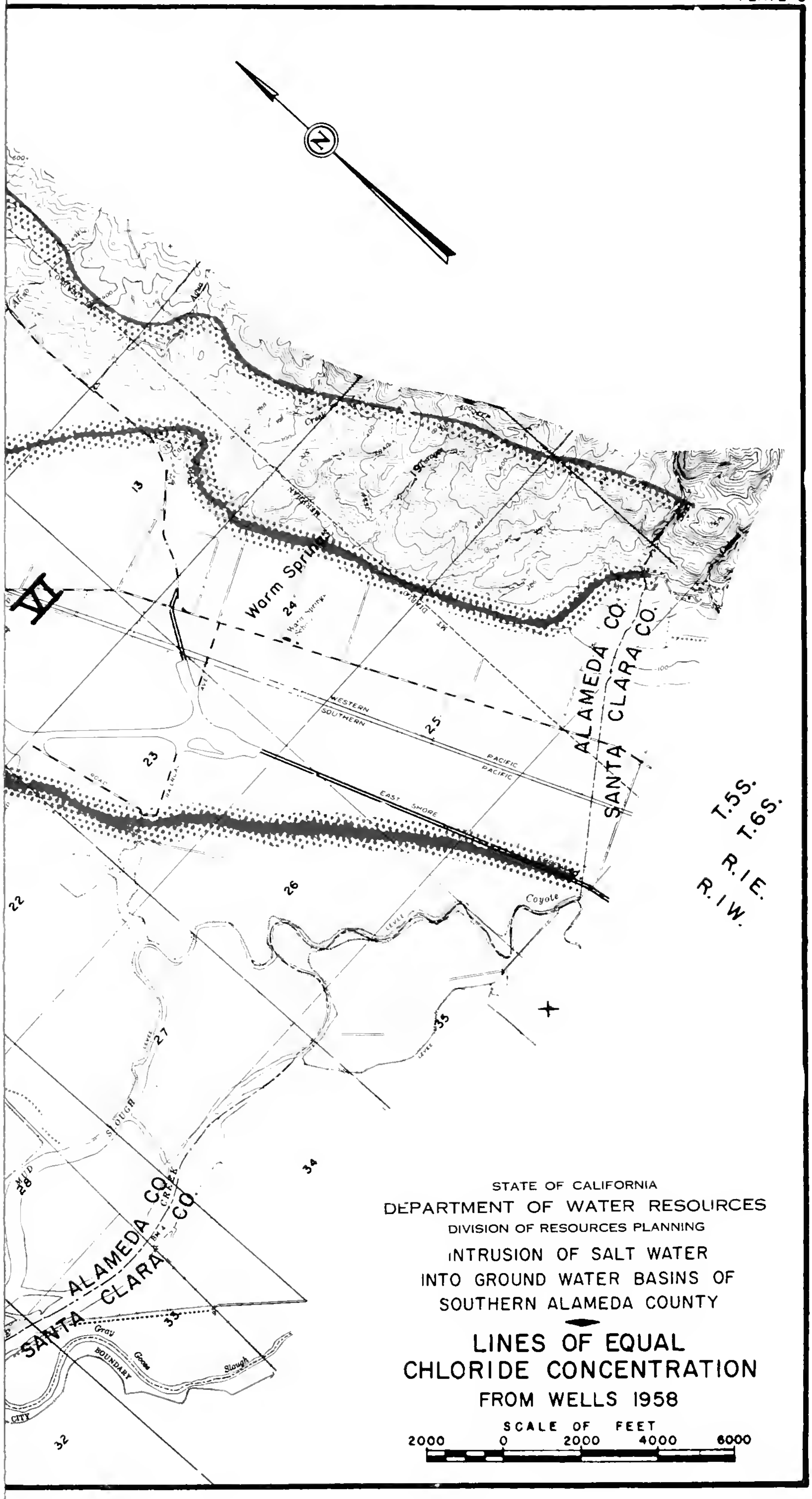
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STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
DIVISION OF RESOURCES PLANNING
INTRUSION OF SALT WATER
INTO GROUND WATER BASINS OF
SOUTHERN ALAMEDA COUNTY
LINES OF EQUAL
CHLORIDE CONCENTRATION
FROM WELLS 1958
SCALE OF FEET
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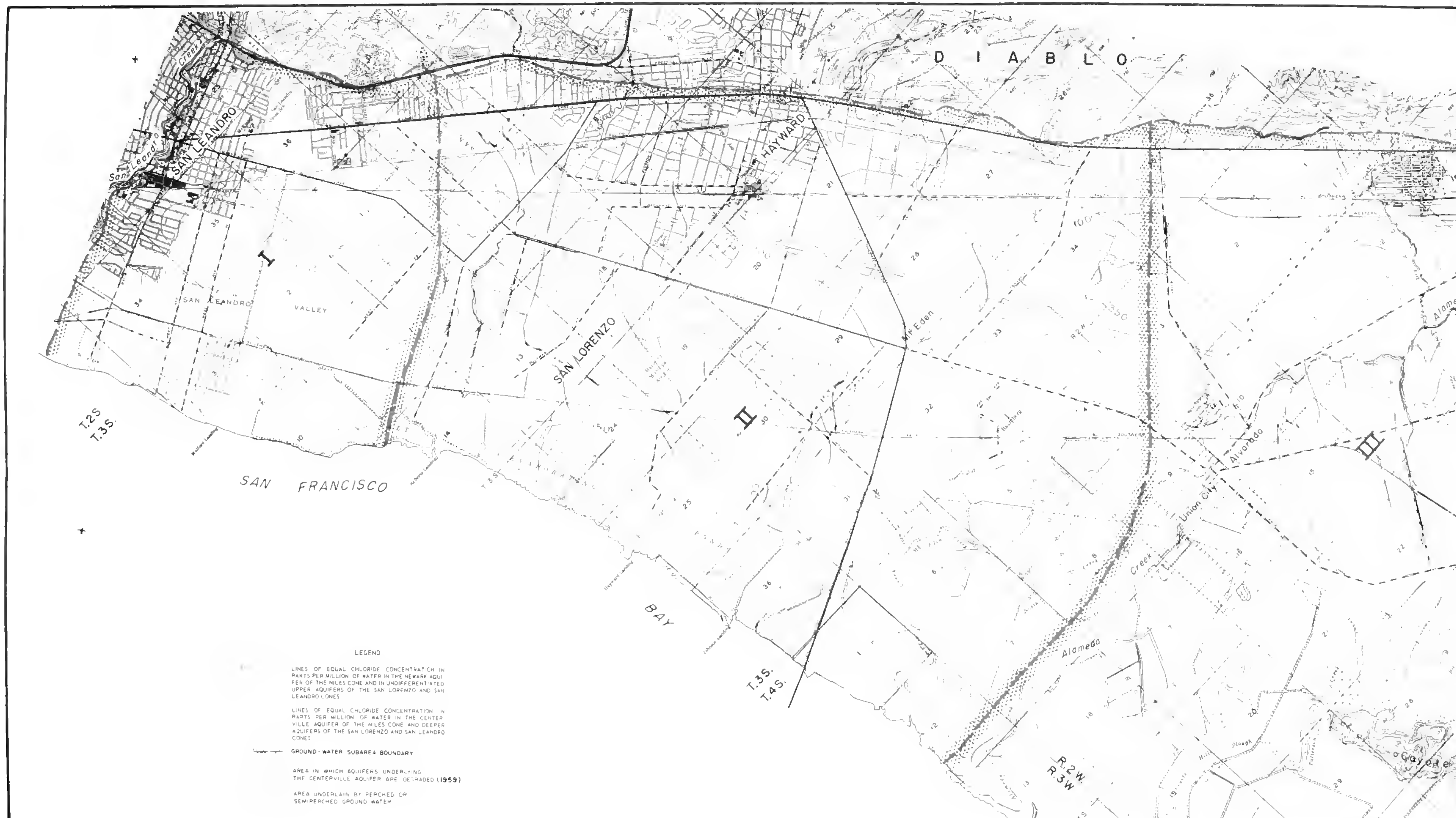
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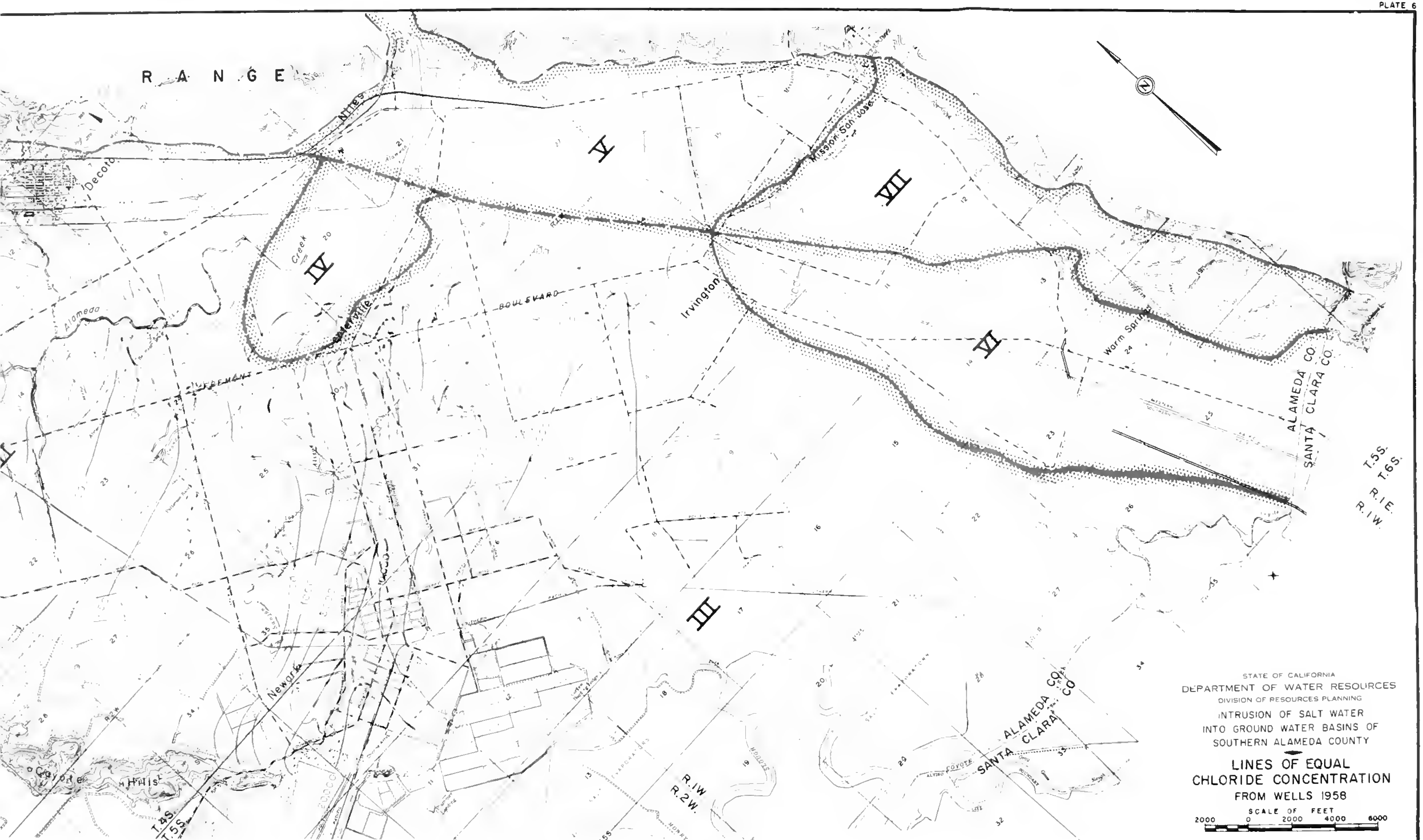
LEGEND
LINES OF EQUAL CHLORIDE CONCENTRATION IN PARTS PER MILLION OF WATER IN THE NEWARK AQUIFER OF THE NILES CONE AND IN UNDIFFERENTIATED UPPER AQUIFERS OF THE SAN LORENZO AND SAN LEANDRO CONES
LINES OF EQUAL CHLORIDE CONCENTRATION IN PARTS PER MILLION OF WATER IN THE CENTERVILLE AQUIFER OF THE NILES CONE AND DEEPER AQUIFERS OF THE SAN LORENZO AND SAN LEANDRO CONES
GROUND-WATER SUBAREA BOUNDARY
AREA IN WHICH AQUIFERS UNDERLYING THE CENTERVILLE AQUIFER ARE DEGRADED (1959)
AREA UNDERLAIN BY PERCHED OR SEMIPERCHED GROUND WATER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STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
DIVISION OF RESOURCES PLANNING
INTRUSION OF SALT WATER
INTO GROUND WATER BASINS OF
SOUTHERN ALAMEDA COUNTY
LINES OF EQUAL
CHLORIDE CONCENTRATION
FROM WELLS 1958
SCALE OF FEET
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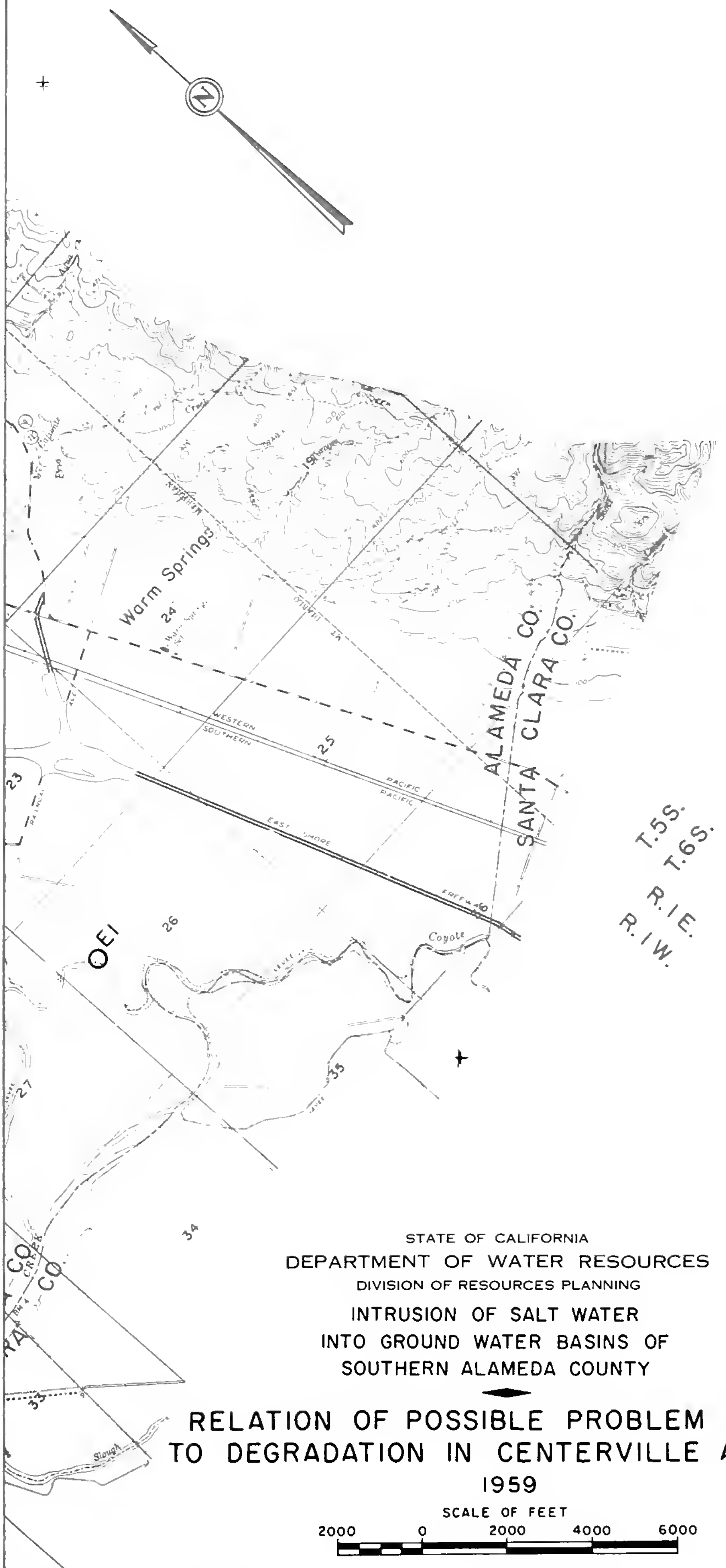

STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
DIVISION OF RESOURCES PLANNING

INTRUSION OF SALT WATER
INTO GROUND WATER BASINS OF
SOUTHERN ALAMEDA COUNTY

RELATION OF POSSIBLE PROBLEM WELLS TO DEGRADATION IN CENTERVILLE AQUIFER

1959

SCALE OF FEET

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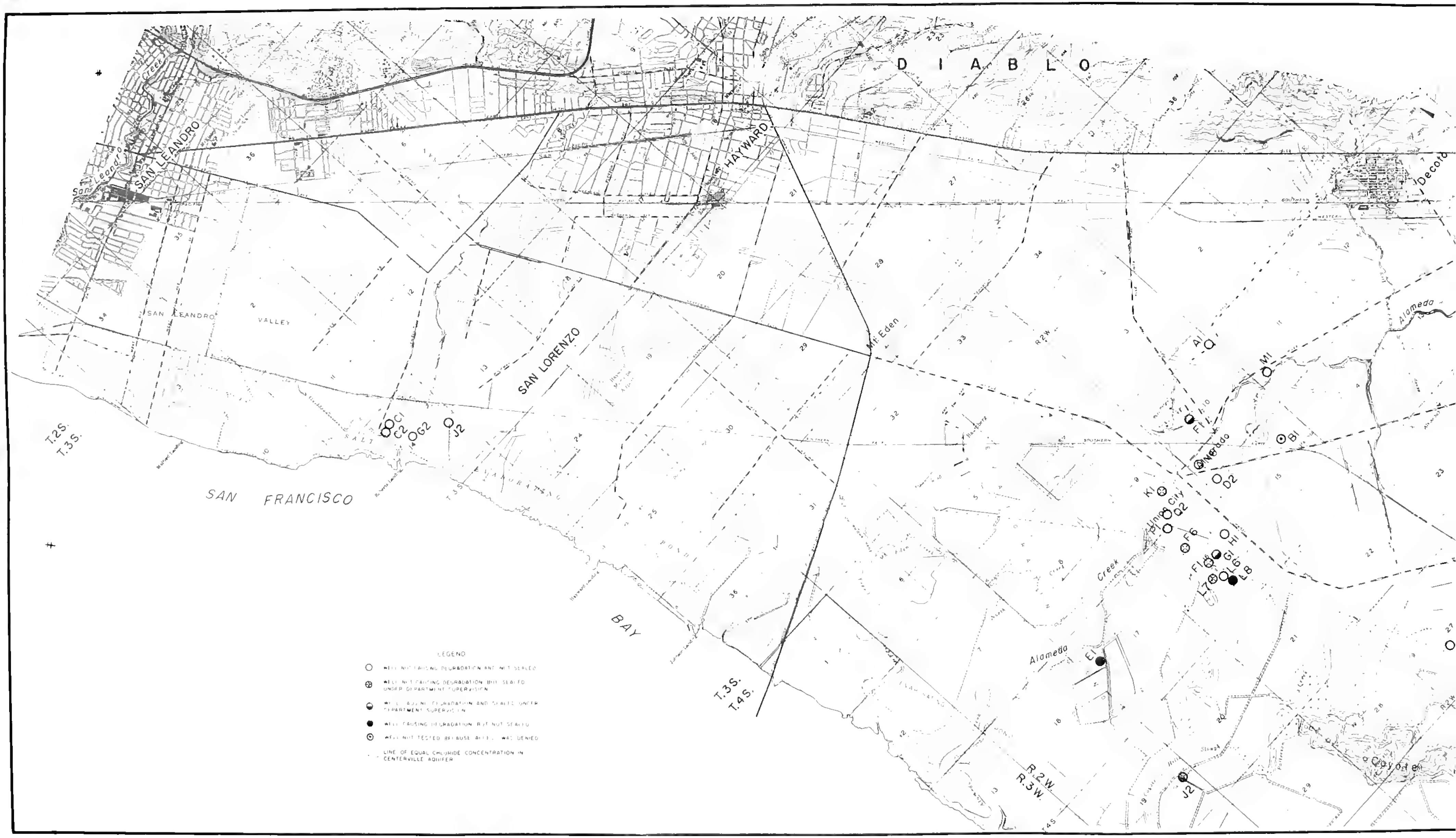

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LEGEND
WELL NOT CAUSING DEGRADATION AND NOT SEALED
WELL NOT CAUSING DEGRADATION BUT SEALED UNDER DEPARTMENT SUPERVISION
WELL CAUSING DEGRADATION AND SEALED UNDER DEPARTMENT SUPERVISION
WELL CAUSING DEGRADATION BUT NOT SEALED
WELL NOT TESTED BECAUSE ACCESS WAS DENIED
LINE OF EQUAL CHLORIDE CONCENTRATION IN CENTERVILLE AQUIFER

STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
DIVISION OF RESOURCES PLANNING

INTRUSION OF SALT WATER
INTO GROUND WATER BASINS OF
SOUTHERN ALAMEDA COUNTY

RELATION OF POSSIBLE PROBLEM WELLS
TO DEGRADATION IN CENTERVILLE AQUIFER
1959

APPENDIX A

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APPENDIX B

SUMMARY OF RESULTS OF TESTING POSSIBLE PROBLEM WELLS

SUMMARY OF RESULTS OF TESTING POSSIBLE PROBLEM WELLS IN SOUTHERN ALAMEDA COUNTY

Well number	Total depth, in feet	Extent of salinity control seal, in feet below land surface	Reason for testing well	Date tested by Contractor	Date tested by Department of Water Resources	Results of tests	Corrective measures taken	Remarks
T3S/R3W-14C1	664	No information	Abandoned deep well; constructed with gravel envelope		Dec. 1958	No leakage demonstrated	None	Well abandoned
T3S/R3W-14C2	574	No information	Abandoned deep well; no information available on salinity control seal		Dec. 1958	No leakage demonstrated	None	Well abandoned
T3S/R3W-14G2	785	0 to 160	Abandoned deep well		Nov. 1958	No leakage demonstrated	None	Well abandoned
T3S/R3W-14J2	834	No seal installed	Abandoned deep well; no salinity control seal installed		Nov. 1958	Well probably not allowing interchange of water between aquifers through well shaft	None	Well abandoned
T4S/R1W-19N1	No information (see remarks)	No information	No information available on depth of well or on salinity control seal; produced water with high chloride content.	Feb. 1959		Well penetrated Newark aquifer only	None	Drill's log previously indicated 260-foot depth. Owner reported approximately 160-foot depth
T4S/R1W-19N7	No information	No information	Abandoned well of unknown depth; produced water with high chloride content.		June 1958	Well penetrated Newark aquifer only	None	Well abandoned
T4S/R1W-28N3	213	Probably no seal installed	Abandoned deep well; driller's log indicated well was perforated in Newark and Centerville aquifers	Aug. 1958		Probable interchange of water between aquifers through well shaft	Well sealed under supervision of Department	Well collapsed while testing; unable to determine quantity of water moving between aquifers
T4S/R1W-28P3	205*	No information	Deep well; no information available on salinity control seal	March 1959		Probable interchange of water between aquifers through well shaft	None	Newark and Centerville aquifers contained water with essentially same low chloride content
T4S/R1W-29C4	145*	No information	Abandoned well; depth uncertain; no information available on salinity control seal		Jan. 1958	Well penetrated Newark aquifer only	None	Well abandoned
T4S/R1W-29E1	291	Possibly 0 to 168	Deep well; information on salinity control seal uncertain; produced water having extremely variable chloride concentrations relatively short periods of time.	Jan. 1959		Well probably not allowing interchange of water between aquifers through well shaft	None	Well restored to operating condition
T4S/R1W-29E6	210	No seal installed	Abandoned deep well; perforated in Newark and Centerville aquifers; produced water with high chloride content	Feb. 1959		Possible interchange of water between aquifers through well shaft	Well sealed under supervision of Department	Well collapsed during testing

SUMMARY OF RESULTS OF TESTING POSSIBLE PROBLEM WELLS IN SOUTHERN ALAMEDA COUNTY
(continued)

Well number	Total depth, in feet	Extent of salinity control seal, in feet below land surface	Reason for testing well	Date tested by Contractor	Date tested by Department of Water Resources	Results of tests	Corrective measures taken	Remarks
T4S/R1W-29F1	151	No seal installed	Driller's log may be erroneously assigned to this abandoned well; depth uncertain; produced water with high chloride content		July 1958	Well penetrated Newark aquifer only	None	Well abandoned
T4S/R1W-29F2	217*	No information	Reported deep well; no information on salinity control seal; produced water with high chloride content; water level indicated interconnection of Newark and Centerville aquifers	Oct. 1958		Probable interchange of water between aquifers through well shaft	No corrective measures possible at time of testing	Contractor could not remove pump because of poor physical condition of well. Detailed testing not possible. Condition of well reported to San Francisco Bay Regional Water Pollution Control Board (No. 2)
T4S/R1W-29J3	229	No seal installed	Deep well; no information available on perforated interval; no salinity control seal installed	March 1959		Well probably not allowing interchange of water between aquifers through well shaft	None	Well restored to operating condition after testing
T4S/R1W-29J4	264	No information	Deep well; no information on perforated interval or on presence of salinity control seal	April 1959		Well probably not allowing interchange of water between aquifers through well shaft	None	Well restored to operating condition after testing
T4S/R1W-29J6	199*	No information	Reported deep well; no information available on control seal; reported perforated in Newark and Centerville aquifers; produced water with high chloride content	March 1959		Well penetrated Newark aquifer only	None	Well restored to operating condition after testing
T4S/R1W-29L7	240*	No information	Reported deep well; abandoned; no information available on salinity control seal; produced water with high chloride content	Jan. 1959		Probable interchange of water between aquifers through well shaft	Well sealed under supervision of Department	Well collapsed below 135 feet during testing. Abandoned after testing
T4S/R1W-29L8	178*	No information	Reported deep well; no information available on salinity control seal	Jan. 1959		Definite interchange of water between aquifers through well shaft. Estimated flow 58 gpm	Centerville aquifer sealed off under supervision of Department	Newark aquifer yields water to well after restoring it to operating condition
T4S/R1W-29M8	218	No seal installed	Abandoned deep well with no salinity control seal: produced water with high chloride content; water level indicated hydraulic connection between Newark and Centerville aquifers	Jan. 1959		Definite interchange of water between aquifers through well shaft. Quantity not determined	Centerville aquifer sealed off under supervision of Department	Well abandoned
T4S/R1W-29P1	266	0 to 113	Abandoned deep well; salinity control seal probably not deep enough to be effective	March 1959		No interchange of water between aquifers through well shaft	Well sealed under supervision of Department	Well located in bottom of flood control channel. Water could enter casing during flood periods and cascade into Centerville aquifer

SUMMARY OF RESULTS OF TESTING POSSIBLE PROBLEM WELLS IN SOUTHERN ALAMEDA COUNTY
(continued)

Well number	Total depth, in feet	Extent of salinity control seal, in feet below land surface	Reason for testing well	Date tested by: Contractor	Date tested by: Department of Water Resources	Results of tests	Corrective measures taken	Remarks
T4S/R1W-30E4	221	No information	Abandoned deep well; no information on salinity control seal; produced water with high chloride content		May 1959	No interchange of water between aquifers through well shaft	None	Well abandoned
T4S/R1W-30H4	180*	No seal installed	Abandoned well; depth unknown; water level indicated hydraulic connection between Newark and Centerville aquifers; produced water with high chloride content	Aug. 1958		Definite interchange of water between aquifers through well shaft. Quantity not determined	Well sealed under supervision of Department	Well abandoned
T4S/R1W-30J1	252	No seal installed	Deep well; no salinity control seal; produced water with high chloride content	March 1959		No interchange of water between aquifers through well shaft	None	Well restored to operating condition after testing
T4S/R1W-30J2	160*	No seal installed	Abandoned well; depth uncertain; produced water with high chloride content		Aug. 1957	Well penetrated the Newark aquifer only	None	Well abandoned
T4S/R1W-30K1	259	No information	Deep well; no salinity control seal information available; produced water with high chloride content	Feb. 1959		No interchange of water between aquifers through well shaft	None	Well restored to operating condition after testing
T4S/R1W-30K2	268	No seal installed	Deep well; no salinity control seal installed; produced water with high chloride content	March 1959		No interchange of water between aquifers through well shaft	None	Well restored to operating condition after testing
T4S/R1W-30K3	276	0 to 168	Deep well; produced water with high chloride content		Aug. 1957	No interchange of water between aquifers through well shaft	None	In March 1958, well was deepened to 502 feet and Centerville aquifer sealed off.
T4S/R1W-30K4	230	No seal installed	Abandoned deep well; no salinity control seal installed	Oct. 1958		Well probably not allowing interchange of water between aquifers through well shaft	Well sealed under supervision of Department	Well abandoned
T4S/R1W-30K5	97*	No information	Abandoned well; depth uncertain; produced water with high chloride content		Oct. 1957	Well penetrated Newark aquifer only	None	Well abandoned
T4S/R1W-30K7	229	No seal installed	Abandoned deep well; no salinity control seal installed; produced water with high chloride content	March 1959		No interchange of water between aquifers through well shaft	Well sealed under supervision of Department	Well abandoned
T4S/R1W-30L1	245	0 to 106	Abandoned deep well; salinity control seal not deep enough to be effective; produced water with high chloride concentrations	March 1959		No interchange of water between aquifers through well shaft	Well sealed under supervision of Department	Well abandoned

SUMMARY OF RESULTS OF TESTING POSSIBLE PROBLEM WELLS IN SOUTHERN ALAMEDA COUNTY
(continued)

Well number	Total depth, in feet	Extent of salinity control seal, in feet below land surface	Reason for testing well	Date tested by: Contractor	Date tested by: Department of Water Resources	Results of tests	Corrective measures taken	Remarks
T4S/R1W-30L2	230*	No information	Abandoned well; reported to be deep; produced water with high chloride content		Jan. 1958	No interchange of water between aquifers through well shaft	None	Well sealed by pouring cement down well shaft from the surface. Adequacy of seal installed in this manner is questionable
T4S/R1W-30N2	225*	No information	Deep well; no information on salinity control seal; produced water with high chloride content	April 1959		No interchange of water between aquifers through well shaft	None	Well restored to operating condition after testing
T4S/R1W-30N3	531	Probably no seal installed	Deep well; probably no salinity control seal installed; produced water with high chloride content for short periods of time immediately after pump started		Feb. 1959	Well probably was allowing small quantities of poor-quality water to move from Newark aquifer into aquifers underlying the Centerville aquifer	None	Well operating at time of testing. Aquifer interchange so small that pumping well for several minutes each day probably removes all poor-quality water from deeper aquifers
T4S/R1W-30N4	215*	No seal installed	Reported deep well; abandoned; no salinity control seal installed; produced water with high chloride content	Feb. 1959		Probable interchange of water between aquifers through well shaft	Well sealed under supervision of Department	Well abandoned after testing
T4S/R1W-30N7	250*	No information	Reported deep well: abandoned; no information on salinity control seal	Jan. 1959		No interchange of water between aquifers through well shaft	Well sealed under supervision of Department	After testing, well sealed and abandoned
T4S/R1W-30P1	256	0 to 161	Abandoned deep well; no information on adequacy of seal					Well could not be found although area was thoroughly searched
T4S/R1W-30Q1	252	Possibly 0 to 159	Deep well; produced poor quality water; possibly no salinity control seal	March 1959		No interchange of water between aquifers through well shaft	None	Pump not reinstalled on well. Cap welded on top of casing and well left idle
T4S/R1W-31F1	250*	No information	Reported deep well produced water with high chloride content; no information on salinity control seal				None	Owner would not permit testing of well. Reported to San Francisco Bay Regional Water Pollution Control Board (No. 2)
T4S/R1W-32E1	278	No seal installed	Deep well; no salinity control seal installed; produced water with high chloride content	Feb. 1959		Definite interchange of poor-quality water between aquifers through well shaft. Calculated flow 1.0 gpm	Well sealed under supervision of Department	Well abandoned
T4S/R1W-32H1	260*	No information	Reported deep well; abandoned; no information on salinity control seal; produced water with high chloride content		June 1959	Possible interchange of water between aquifers through well shaft	Well sealed under supervision of Department	Well abandoned

SUMMARY OF RESULTS OF TESTING POSSIBLE PROBLEM WELLS IN SOUTHERN ALAMEDA COUNTY
(continued)

Well number	Total depth, in feet	Extent of salinity control seal, in feet below land surface	Reason for testing well	Date tested by Contractor	Date tested by Department of Water Resources	Results of tests	Corrective measures taken	Remarks
T4S/R1W-32K1	265	0 to 117	Deep well; salinity control seal probably not effective; produced water with high chloride conteot	April 1959		No interchange of water between aquifers through well shaft	None	Well restored to operating condition after testing
T4S/R1W-32K7	238*	No information	Water level indicated deep well; no information available on salinity control seal; produced water with high chloride content	Feb. 1959		No interchange of water between aquifers through well shaft	None	Well restored to operating condition after testing
T4S/R1W-32K9	261	0 to 159	Abandoned deep well; produced water with high chloride content	Aug. 1958		No interchange of water between aquifers through well shaft	Well sealed under supervision of Department	Well abandoned
T4S/R1W-32Q1	89*	No information	Abandoned well; produced water with high chloride content; no information on salinity control seal		Jan. 1958	Well penetrated the Newark aquifer only	None	Well abandoned
T4S/R1W-33A1	201	Probably no seal installed	Deep well; probably no salinity control seal installed	Feb. 1959		Well had beea perforated in both Newark and Centerville aquifers; definite interchange of water through well shaft	None	Chloride content of water in both aquifers was low. Well restored to operating condition
T4S/R1W-33D1	315	No information	Abandoned deep well; no information on salinity control seal; produced water with high chloride content	March 1959		Probable interchange of water between aquifers through the annular space surrounding well casing. Flow not determined	Lower aquifers sealed off from Newark aquifer under supervision of Department	Well abandoned
T4S/R1W-33F1	180	No information	Water-levels indicated hydraulic connection between Newark and Centerville aquifers; produced water with high chloride content	Feb. 1959		Well penetrated the Newark aquifer only	None	Well abandoned
T4S/R1W-33F5	101*	No information	Abandoned well; no information on depth; salinity seal uncertain.	Oct. 1958		Well penetrated the Newark aquifer only.	None	Well abandoned
T4S/R1W-33F6	263	Probably 0 to 155	Abandoned deep well; information on salinity control seal uncertain; produced water with relatively high chloride content.	Oct. 1958		No interchange of water between aquifers through well shaft	None	Well abandoned
T4S/R1W-34D2	220*	No information	Reported deep well; abandoned; no information on salinity control seal.		Aug. 1958	No interchange of water between aquifers through well shaft	Well sealed under supervision of Department.	Well abandoned

SUMMARY OF RESULTS OF TESTING POSSIBLE PROBLEM WELLS IN SOUTHERN ALAMEDA COUNTY
(continued)

Well number	Total depth, in feet	Extent of salinity control seal, in feet below land surface	Reason for testing well	Date tested by Contractor	Date tested by Department of Water Resources	Results of tests	Corrective measures taken	Remarks
T4S/R1W-34N1	240*	No information	Reported deep well; abandoned; no information on salinity control seal; water levels indicated connection of Newark and Centerville aquifers; reports of falling water in well.	April 1959		Definite interchange of water between aquifers through well shaft.	Well sealed under supervision of Department	Newark aquifer contained good-quality water
T4S/R2W-9K1	440	Probably no seal installed	Deep well; probably no salinity control seal installed; chloride content of water increased with pumping time	May 1959		Possible interchange of water between aquifers through well shaft. Quality of water in Newark aquifer better than that in Centerville aquifer	Well sealed under supervision of Department	Well casing damaged during testing. Seven-inch liner placed from surface down to depth of 135 feet and sealed with grout. Well restored to operating condition
T4S/R2W-9P1	740	No information	Deep well; gravel-packed; no information on salinity control seal	March 1959		Probably no interchange of water between aquifers through well shaft. Aquifers underlying Centerville aquifer contained water with high chloride content	None	Well restored to operating condition after testing
T4S/R2W-9Q2	648	Probably no seal installed	Deep well; probably no salinity control seal installed; possibly gravel-packed	March 1959		Probably no interchange of water between aquifers through well shaft. Aquifers underlying the Centerville aquifer contained water with high chloride content	None	Well restored to operating condition after testing
T4S/R2W-10A1	527	Probably no seal installed	Abandoned deep well; probably no salinity control seal installed	May 1959		Probably no interchange of water between aquifers through well shaft	None	Well abandoned
T4S/R2W-10F1	530	Probably no seal installed	Abandoned deep well; probably no salinity control seal installed		Feb. 1959	Near-surface water of poor quality was entering well casing	Well sealed under supervision of Department	Well abandoned
T4S/R2W-10N6	576	0 to 200	Deep well; produced water with high chloride content		May 1959	Deeper aquifers penetrated by well possibly yielded the water with high chloride content	Owner sealed off lower portion of well (from depth of 497 feet to bottom) after testing	Well in operating condition
T4S/R2W-11M1	100*	No information	Well depth uncertain; no information on salinity control seal; produced water with high chloride content	April 1959		Well penetrated the Newark aquifer only	None	Well restored to operating condition after testing
T4S/R2W-15B1	197	Probably no seal installed	Well probably deep enough to penetrate Centerville aquifer; produced water with high chloride content; probably no salinity control seal installed; water levels indicated connection between Newark and Centerville aquifers			Possible interchange of water between aquifers indicated by limited tests	None	Owner would not permit detailed testing of this well. Reported to San Francisco Bay Regional Water Pollution Control Board (No. 2)

SUMMARY OF RESULTS OF TESTING POSSIBLE PROBLEM WELLS IN SOUTHERN ALAMEDA COUNTY
(continued)

Well number	Total depth, in feet	Extent of salinity control seal, in feet below land surface	Reason for testing well	Date tested by: Contractor	Date tested by: Department of Water Resources	Results of tests	Corrective measures taken	Remarks
T4S/R2W-15D2	300	Possibly 0 to 80	Abandoned deep well; no effective salinity control seal installed	April 1959		No interchange of water between aquifers through well shaft	None	Well restored to condition existing prior to testing
T4S/R2W-16F1	500*	No information	Abandoned deep well; no information on salinity control seal	May 1959		Near-surface water of poor quality entering casing. Probably no interchange of water between aquifers through well shaft	Grout seal placed from 165 to 125 feet in depth under supervision of Department.	Well abandoned
T4S/R2W-16F6	258	0 to 130	Abandoned deep well	April 1959		No leakage demonstrated	Well sealed under supervision of Department	Well collapsed during testing. Well abandoned
T4S/R2W-16G1	398	No seal installed	Abandoned deep well; no salinity control seal installed; produced water with high chloride content	March 1959		Probable interchange of water between aquifers through well shaft. Flow not determined	Grout seal placed in well from 243 to 230 feet in depth under supervision of Department	Well abandoned
T4S/R2W-16H1	206	No information	Abandoned deep well; no information on salinity control seal	March 1959		No interchange of water between aquifers through well shaft	None	Well abandoned
T4S/R2W-16L6	403	0 to 250	Deep well; produced water with high chloride content	March 1959		No interchange of water between aquifers through well shaft	None	Well restored to operating condition after testing
T4S/R2W-16L7	379	No information	Abandoned deep well; no information on salinity control seal; produced poor quality water	March 1959		Probably no interchange of water between aquifers through well shaft	Grout seal placed in well from 170 to 148 feet in depth under supervision of Department	Well had collapsed below a depth of 150 feet prior to testing. Well abandoned
T4S/R2W-16L8	313	Probably no seal installed	Abandoned deep well; probably no salinity control seal installed; produced water with high chloride content	March 1959		Near-surface water with 20,700 ppm chlorides entering well casing at high tide. Approximately 0.5 gpm entering casing at a depth of about 12 feet and moving into deeper aquifers	None	Condition of well reported to owner and to San Francisco Bay Regional Water Pollution Control Board (No. 2)
T4S/R2W-17E1	277*	No information	Reported deep well; no information on salinity control seal; produced water with high chloride content	June 1959		Near-surface water with 25,000 ppm chlorides entering casing at time of testing. Tests indicated very little circulation of water in well; thus interchange of water between Newark and deeper aquifers probably slight	None	Well restored to operating condition after testing. Condition of well reported to owner and to San Francisco Bay Regional Water Pollution Control Board (No. 2)

SUMMARY OF RESULTS OF TESTING POSSIBLE PROBLEM WELLS IN SOUTHERN ALAMEDA COUNTY
(continued)

Well number	Total depth, in feet	Extent of salinity control seal, in feet below land surface	Reason for testing well	Date tested by Contractor	Date tested by Department of Water Resources	Results of tests	Corrective measures taken	Remarks
T4S/R2W-19J2	308*	No information	Reported deep well; abandoned; no information on salinity control seal; water levels indicate connection between Newark and Centerville aquifers	April 1959		No leakage demonstrated	Well sealed under supervision of Department	Well abandoned
T4S/R2W-24L2	215	Probably no seal installed	Deep well; probably no salinity control seal installed			Possible interchange of water between aquifers indicated by change in quality of water over periods of time	None	Owner would not permit detailed testing of this well. Reported to San Francisco Bay Regional Water Pollution Control Board (No. 2)
T4S/R2W-25A1	261	0 to 153	Abandoned deep well; produced water with high chloride content		May 1959	No interchange of water between aquifers through well shaft	None	Well abandoned
T4S/R2W-25F1	205	Probably no seal installed	Abandoned deep well; probably no salinity control seal installed; produced water with high chloride content; water level indicated connection between Newark and Centerville aquifers	July 1958		Probably no interchange of water between aquifers through well shaft	None	Well had collapsed prior to testing. Drilling contractor unable to open well to depth of Centerville aquifer. Well abandoned after testing
T4S/R2W-25K1	310	Probably no seal installed	Abandoned deep well; probably no salinity control seal; produced water with high chloride content		May 1959	Probably no interchange of water between aquifers through well shaft	None	Well abandoned
T4S/R2W-25R1	256*	No information	Reported deep well; abandoned; no information on salinity control seal	March 1959		Definite interchange of water between aquifers through the annular space around well casing. Estimated 1.0 gpm flow	Grout seal placed from 190 to 175 feet in depth under supervision of Department.	Well abandoned
T4S/R2W-26E1	210*	No information	Reported deep well; no information on salinity control seal; produced water with high chloride content; reported to be perforated in both Newark and Centerville aquifers	April 1959		Probable interchange of water between aquifers through well shaft	None	Chloride content satisfactory in both Newark and Centerville aquifers. Well restored to operating condition after testing
T4S/R2W-26R1	201*	No information	Reported deep well; abandoned; no information on salinity control seal	Feb. 1959		No interchange of water between aquifers through well shaft	Newark aquifer sealed off with grout seal under supervision of Department	Well abandoned
T4S/R2W-27K2	346	Possibly 0 to 111	Abandoned deep well; possibly no salinity control seal installed		Feb. 1959	No leakage demonstrated	None	Well collapsed below [illegible]-foot depth prior to testing
T4S/R2W-27L2	281	Probably no seal installed	Abandoned deep well; probably no salinity control seal installed		Dec. 1958	Probably no interchange of water between aquifers through well shaft	None	Well abandoned

SUMMARY OF RESULTS OF TESTING POSSIBLE PROBLEM WELLS IN SOUTHERN ALAMEDA COUNTY
(continued)

Well number	Total depth, in feet	Extent of salinity control seal, in feet below land surface	Reason for testing well	Date tested by: Contractor	Date tested by: Department of Water Resources	Results of tests	Corrective measures taken	Remarks
T4W/R2W-36H1	250	0 to 110	Abandoned deep well; salinity control seal too shallow to be effective		May 1958	Probably no interchange of water between aquifers through well shaft	None	Well abandoned
T4S/R2W-36H2	240	Probably no seal installed	Abandoned deep well; probably no salinity control seal installed		Jan. 1959	Probably no interchange of water between aquifers through well shaft	None	Well abandoned
T4S/R2W-36K1	216	Probably no seal installed	Abandoned deep well; probably no salinity control seal installed; produced water with a high chloride content		Aug. 1958	Probably no interchange of water between aquifers through well shaft	None	Well abandoned
T5S/R1W-3B1	260	Probably no seal iostalled	Abandoned deep well; probably no salinity control seal installed		Oct. 1958	Probably no interchange of water between aquifers through well shaft	None	Well restored to operating condition after testing
T5S/R1W-3N1	120*	No ioformation	Abandoned well; depth uncertain; oo information available on salinity control seal		June 1958	Well penetrated Newark aquifer only	None	Well abandoned
T5S/R1W-4B1	269	Probably oo seal installed	Abandoned deep well; probably no salinity control seal installed; produced water with high chloride content		Sept. 1959	Probably no interchange of water betweeo aquifers through well shaft	None	Well abandoned
T5S/R1W-4C1	267	Possibly 0 to 165	Abandoned deep well; possibly no salinity control seal installed; produced water with high chloride content		Sept. 1959	Probably no interchange of water between aquifers through well shaft	None	Well abandoned
T5S/R1W-4D2	247	No information	Abandoned deep well; no information on salinity control seal; water level indicated connection between Newark and Centerville aquifers	Jan. 1959		Definite interchange of water between aquifers through well casing. Flow not determined	Well sealed under supervision of Department	Well abandoned
T5S/R1W-4E1	No information	No information	Water level indicated deep well; no information on salinity cootrol seal; produced water with high chloride conteot	Jan. 1959		No interchange of water between aquifers through well shaft	None	Well restored to operating condition after testing
T5S/R1W-4F1	97*	No informatioo	Abandoned well; depth uncertain; no information on salinity control seal		Dec. 1958	Well penetrated Newark aquifer only	None	Well abandoned
T5S/R1W-4G1	279	Possibly 0 to 144	Deep well; possibly no salinity control seal iostalled; produced water with high chloride content	Feb. 1959		No interchange of water between aquifers through well shaft	None	Well restored to operating conditioo after testing

SUMMARY OF RESULTS OF TESTING POSSIBLE PROBLEM WELLS IN SOUTHERN ALAMEDA COUNTY
(continued)

Well number	Total depth, in feet	Extent of salinity control seal, in feet below land surface	Reason for testing well	Date tested by: Contractor	Date tested by: Department of Water Resources	Results of tests	Corrective measures taken	Remarks
T5S/R1W-5G1	261	No seal installed	Deep well; no salinity control seal installed; produced water with high chloride content	Jan. 1959		No interchange of water between aquifers through well shaft	None	Well restored to operating condition after testing
T5S/R1W-8A2	200*	No information	Abandoned well reported perforated in both Newark and Centerville aquifers	Jan. 1959		Well penetrated Newark aquifer only	None	Well abandoned
T5S/R1W-8F1	224*	No information	Abandoned well: reported deep; no information on salinity control seal	Apr. 1959		Probable interchange of water between aquifers through well shaft. Flow not determined	Well sealed under supervision of the Department	Clearance between pump bowls and well casing very small, possibly sealed by chemical deposits. Movement of water from Newark to Centerville very limited. Well abandoned
T5S/R1W-8P3	No information	No information	Abandoned well; no information on salinity control seal		May 1959	Well penetrated Newark aquifer only	None	Well abandoned
T5S/R1W-8R2	No information	No information	Abandoned well; no information on salinity control seal	May 1959		Well penetrated Newark aquifer only	None	Well abandoned
T5S/R1W-17H2	498	Probably no seal installed	Abandoned deep well; probably no salinity control seal installed		Jan. 1958	Probably no interchange of water between aquifers through well shaft	None	Well abandoned
T5S/R1W-26E1	380*	No information	Abandoned well; reported deep; no information on salinity control seal; produced water with high chloride content		Apr. 1958	Probably no interchange of water between aquifers through well shaft	None	Well possibly subjected to flooding with saline bay water. Well restored to condition existing prior to testing
T5S/R2W-1E1	430	No seal installed	Abandoned deep well; no salinity control seal installed		June 1958	Probably no interchange of water between aquifers through well shaft	None	Well abandoned
T5S/R2W-2A1	250*	Probably no seal installed	Abandoned deep well; probably no salinity control seal installed; owner reported that well was constructed very poorly and had been installed with a gravel envelope	Sept. 1958		No leakage demonstrated	Well sealed under supervision of Department	Perforated in both Newark and Centerville aquifers. Very fine-grained sediment had moved through perforations and gravel envelope and probably prevented interchange of water between aquifers
T5S/R2W-2B1	265*	No information	Reported deep well; abandoned; no information on control seal	Mar. 1959		No interchange of water between aquifers through well shaft	Well sealed under supervision of Department	Although well was not allowing interchange of water between aquifers at time of testing, it probably had [illegible] so in the past. Well abandoned after testing.
T5S/R2W-2C1	287	No seal installed	Deep well; no salinity control seal installed		Jan. 1958	No leakage demonstrated		Testing limited to obtaining analyses of water produced by well and comparing water levels with those of adjacent deep wells

SUMMARY OF RESULTS OF TESTING POSSIBLE PROBLEM WELLS IN SOUTHERN ALAMEDA COUNTY
(continued)

Well number	Total depth, in feet	Extent of salinity control seal, in feet, below land surface	Reason for testing well	Date tested by: Contractor	Date tested by: Department of Water Resources	Results of tests	Corrective measures taken	Remarks
T5S/R2W-2C3	200*	No information	Abandoned well; reported deep; no information on salinity control seal; owner reported hearing water falling down well	Jan. 1959		No leakage demonstrated	Well sealed under supervision of Department	Well had evidently allowed interchange of water between aquifers in the past. Abandoned after testing and sealing
T5S/R2W-2M1	No information	No information	Abandoned well; water levels indicated deep well; no information on salinity control seal	July 1958		No interchange of water between aquifers through well shaft	Well sealed under supervision of Department	This well had been subjected to flooding by saline bay water during high tides
T5S/R2W-11H1	370	Possibly 0 to 100	Abandoned deep well; data on salinity control seal uncertain	April 1959		Possible interchange of water between aquifers (see remarks)	Well "sealed" in manner not shown to be adequate	Fine-grained sedimentary material had moved into well and gravel-envelope and probably restricted movement of water from one aquifer into another. Reported to the San Francisco Bay Regional Water Pollution Control Board (No. 2)

* Indicates reported depth